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Sodium and Specialty Cyanides Production Facility

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Abstract

Sodium cyanide and specialty cyanide production are essential operations for various industrial processes, with primary applications in mining and mineral processing. Sodium cyanide, despite the high toxicity inherent in the material and its production process, is expected to grow 5% annually, with a projected global demand of 1.1 million tonnes in 2018. This report details a process design for producing sodium cyanide through the use of two intermediate reactions and successive downstream separations. The first major step is the production of hydrogen cyanide gas from ammonia and methane derived from natural gas, via the industry standard Andrussow reaction over a platinum-rhodium gauze catalyst. Aqueous sodium cyanide is produced via a neutralization reaction of absorbed hydrogen cyanide gas with aqueous sodium hydroxide. Downstream processes include the crystallization of solid sodium cyanide from the aqueous product, with the solid product being removed from slurry and brought to low-moisture content through a series of solid-liquid separations. The low-moisture solids are formed into the final briquette product, which is 97.7% sodium cyanide by mass at a capacity of 61.5M tonnes/year, and containing sodium carbonate as the principal impurity. Unconverted ammonia is recovered and recycled back to the feed of the HCN reactor, increasing the molar percent yield of hydrogen cyanide gas on the basis of fed ammonia from 60% to 70.9%. The project requires $35.6MM in Total Capital Investment and produces a Net Present Value of $72.5MM after 15 operating years and presents an Internal Rate of Return of 48.4%. The project will break even in its third operating year when it hits full production capacity. The design is recommended due to its strong return on investment and high resilience to market fluctuations.

Disciplines

Biochemical and Biomolecular Engineering | Chemical Engineering | Engineering

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Dear Professor Talid Sinno and Mr. Bruce M. Vrana,

Enclosed is a potential process design for the industrial production of sodium and specialty cyanides. The proposed plant will be located at a manufacturing site in Rochester, Nevada that will have access to natural gas, electricity, and limited aqueous waste treatment. The site host company is a medium sized gold/silver ore mining company. The plant is capable of producing 61.5 Mtonnes of sodium cyanide and 2.1 Mtonnes of potassium cyanide per year. The solid sodium cyanide product will have a purity on a mass basis of 97.7% with sodium carbonate as its principal impurity and be sold as pressed solid briquettes. The process employs measures to recycle unconverted raw material, limit gaseous emissions, and enhance overall worker safety.

The plant will operate for 24 hours a day, 330 days a year. Rigorous profitability analysis was conducted in order to project cash flows for 15 years. The total capital investment of the plant is \$35.6MM and the expected NPV of the project is \$72.5MM. The estimated IRR of the project is 48.4% and will breakeven in its third operating year when it hits its full production capacity. We recommend moving forward in production using the outlined process, but to continue research in the areas of reactor optimization, emission control, solids drying, and market pricing of raw materials.

Sincerely,

Parth Desai　　Nick Baylis　　Kyle Kuhns

Sodium and Specialty Cyanides Production Facility

Nick Baylis | Parth Desai | Kyle Kuhns

Project Submitted to: Prof. Bruce Vrana and Prof. Talid Sinno
Project Proposed by: Mr. Stephen Tieri

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Section 1: Abstract

Sodium cyanide and specialty cyanide production are essential operations for various industrial processes, with primary applications in mining and mineral processing. Sodium cyanide, despite the high toxicity inherent in the material and its production process, is expected to grow 5% annually, with a projected global demand of 1.1 million tonnes in 2018. This report details a process design for producing sodium cyanide through the use of two intermediate reactions and successive downstream separations. The first major step is the production of hydrogen cyanide gas from ammonia and methane derived from natural gas, via the industry standard Andrussow reaction over a platinum-rhodium gauze catalyst. Aqueous sodium cyanide is produced via a neutralization reaction of absorbed hydrogen cyanide gas with aqueous sodium hydroxide. Downstream processes include the crystallization of solid sodium cyanide from the aqueous product, with the solid product being removed from slurry and brought to low-moisture content through a series of solid-liquid separations. The low-moisture solids are formed into the final briquette product, which is 97.7% sodium cyanide by mass at a capacity of 61.5M tonnes/year, and containing sodium carbonate as the principal impurity. Unconverted ammonia is recovered and recycled back to the feed of the HCN reactor, increasing the molar percent yield of hydrogen cyanide gas on the basis of fed ammonia from 60% to 70.9%. The project requires $35.6MM in Total Capital Investment and produces a Net Present Value of $72.5MM after 15 operating years and presents an Internal Rate of Return of 48.4%. The project will break even in its third operating year when it hits full production capacity. The design is recommended due to its strong return on investment and high resilience to market fluctuations.

Section 2: Introduction

Sodium cyanide (NaCN) is a water soluble inorganic salt that is a white crystalline solid at ambient temperature and pressure. It has a high toxicity, and thus can be deadly to humans through ingestion, dust inhalation, and skin absorption through open wounds.[1] It is a highly basic substance, and when wet, small amounts will revert back into hydrogen cyanide (HCN) gas though hydrolysis, a key intermediate in the production of sodium and other specialty cyanides. Hydrogen cyanide exists as a colorless gas at temperatures just above ambient conditions (boiling point of 78.8°C), and can be detected by its faint almond-like odor. Hydrogen cyanide gas is also extremely poisonous to humans at very low concentrations.

Despite the high toxicities inherent in the material and its production, sodium cyanide is a key component in various industrial applications, and is most widely used in mining and metal processing operations. Using low concentration sodium cyanide dissolved in water, gold can be extracted from ore by forming a water soluble coordination complex with the cyano group. This reaction is modelled by the Elsner Equation (Equation 1).

$$4\ Au\ (s) + 8\ NaCN\ (aq) + O2\ (g) + 2\ H2O\ (l) = 4\ Na[Au(CN)2]\ (aq) + 4\ NaOH\ (aq) \quad (1)$$

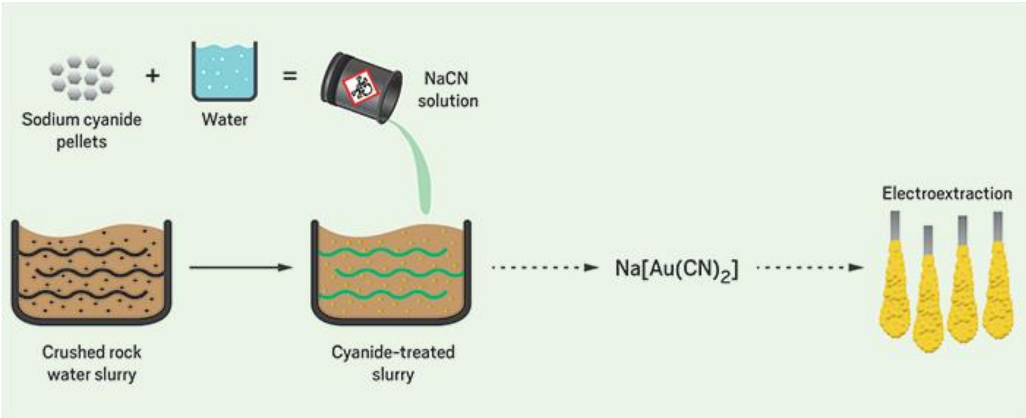

Figure 2.1. Crushed rock is mixed into water slurry and treated with 20-23 wt% sodium cyanide solution, which complexes with gold in the ore. Electroextraction removes gold from the solution.

[1] "Sodium Cyanide: Systemic Agent" <https://www.cdc.gov/niosh/ershdb/emergencyresponsecard_29750036.html>

Our team is tasked with designing a plant capable of producing 60,000 tonnes/yr of high purity sodium cyanide in a safe and environmentally sound manner. The manufacturing site will be located in Rochester, Nevada and will have access to natural gas and electricity, but limited aqueous waste treatment. The site host company is a medium sized gold/silver ore mining recovery company.

In addition to producing sodium cyanide, we are also tasked with producing 2,000 tonnes/year of specialty cyanides: lithium cyanide (LiCN), potassium cyanide (KCN), and/or calcium cyanide ($CaCN_2$). Lithium cyanide is not used in the mining industry, so its production would not be beneficial to the business partners to whom we are selling sodium cyanide. Potassium and calcium cyanide are both used in the mining industry, but potassium cyanide can be produced with the same equipment that will be in place for sodium cyanide production, whereas calcium cyanide would require different equipment. As such, our plant will produce potassium cyanide in addition to sodium cyanide since it is within the same target market, and its production method is essentially identical.

Section 3: Objective Time Chart

Project Leaders: Nick Baylis, Parth Desai, and Kyle Kuhns

Specific Goals

- Develop plant with the capacity to produce 60 M tonnes/yr of sodium cyanide and 2 M tonnes/yr of speciality cyanides
- High product purity, minimization of emissions and handling of hazardous material

Project Scope

In Scope:

- Produce 60 M tonnes/yr of sodium cyanide and 2 M tonnes/yr of specialty cyanide
- Produce product with 98% ±1% purity
- Determine equipment units required and associated operating conditions
- Accurately size equipment and determine bare module costs
- Determine methods to integrate heat between process streams and minimize utility requirements
- Recover and recycle unconverted materials to maximum economic extent
- Implement proper safety measures to minimize detect, mitigate, and contain hazardous hydrogen cyanide release
- Minimize emissions of ammonia and hydrogen in accordance with state and federal emissions legislations

Out of Scope:

- Kinetic analysis of HCN reaction
- Study of catalyst life-time
- Design of process control systems
- Rigorous waste-treatment design

Deliverables

- Develop complete process flow diagram with material and energy balances
- Financial and profitability analysis of process including sensitivity analysis to raw material pricing

Process Development Timeline

- Completion of preliminary material balance [Jan. 30]
- Completion of base case material balance [Feb. 20]
- Completion of major equipment design [Mar. 27]
- Completion of financial analysis [Apr. 3]
- Completion of written report [Apr. 17]

Section 4: Innovation Map

Not Applicable for this report

Section 5: Market and Competitive Analysis

Sodium cyanide is used throughout the world, primarily as a reagent in the mining industry for the isolation of precious ores. Approximately 90% of sodium cyanide is used for gold and silver processing in North American markets and around 78% is used for this purpose worldwide.[2] Aside from its use in the mining industry, sodium cyanide is also used as feedstock to produce compounds including cyanuric chloride, cyanogen chloride, and various types of nitriles. Another major market for cyanides is the electroplating segment which constitutes approximately 9% of worldwide demand, where sodium cyanide is used to improve the durability and reduce corrosion in automotive parts.

In 2016, the global sodium cyanide capacity was over 1.19 million tonnes with a global demand of approximately 759,000 tonnes.[3] According to a recent market study released by Technavio, the global market is expected to grow at a CAGR (compounded annual growth rate) of over 5.14% until 2021.[4] The precious metal mining industry is expected to grow at a CAGR of 3-4% in Africa and 2-3% in the Asia Pacific and Oceania regions, driving similar growth in sodium cyanide consumption. Demand from these regions will represent key drivers for the sodium cyanide market in the near future. By contrast, the US mining industry is only expected to experience a marginal increase in the upcoming years and is highly dependent on favorable policy changes.

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[2] Sodium Cyanide - Chemical Economics Handbook. (2016, September). Retrieved April 18, 2018, from https://ihsmarkit.com/products/sodium-cyanide-chemical-economics-handbook.html

[3] Category Intelligence on Sodium Cyanide | Market Intelligence Report | Size, Trends, Outlook, Prize & Forecast. (2017, November 01). Retrieved April 14, 2018, from https://www.beroeinc.com/category-intelligence/sodium-cyanide-market/

[4] Global Sodium Cyanide Market - Analysis, Technologies & Forecasts to 2021 - Research and Markets. (2017, October 09). Retrieved April 14, 2018, from https://www.businesswire.com/news/home/20171009005412/en/Global-Sodium-Cyanide-Market---Analysis-Technologies

The top global suppliers of sodium cyanide as of 2016 include Anhui Shuguang, Cyanco, Hebei Chengxin, Chemours, and Orica, with plant capacities ranging from 20,000 to 65,000 tonnes per year. The potassium cyanide market is also projected to grow over the next several years -- a report by FiorMarkets projects a CAGR of 2.2% by 2022 of the global potassium cyanide market. [5] Key players operating in the potassium cyanide market include Sreenivasa Industries, Prominex Precious Mineral Resources, and GFS Chemicals. [6]

[5]Global Potassium Cyanide Market Outlook 2017-2022. (2018, February). Retrieved April 14, 2018, from https://www.fiormarkets.com/report/global-potassium-cyanide-market-outlook-2017-2022-206609.html
[6]Global Kcn (Gold Potassium Cyanide) Market Industry Analysis And Forecast To 2027. (2016, April 8). Retrieved April 14, 2018, from https://www.marketresearchfuture.com/articles/gold-potassium-cyanide-kcn-market

Section 6: Customer Requirements

The project objective requires 60,000 tonnes of 98% ± 1% mass purity sodium cyanide briquettes to be produced per year. Industry leader Chemours (formerly E.I. du Pont Nemours and Company) maintains the world's largest solid sodium cyanide plant, producing solid product with mass purity of 98%. As one of the largest producers of sodium cyanide, Chemours's product purity represents the industry standard.

In order to reach this high purity level, this design utilizes a relatively new mechanism to remove the principal product impurity, sodium carbonate (Na_2CO_3), which is generated as a byproduct during the process. This method will be discussed further in Section 14. This proposed process ultimately generates a final solid product that is 97.65% by mass sodium cyanide in a compacted briquette form with dimensions of 1.80x1.80x1 in, which in line with traditional mining operation requirements. This purity meets the project objective requirements and is competitive by market standards. Sodium carbonate is present in the final product at 0.597 % by mass, with sodium hydroxide and trace impurities composing the balance.

This process design produces product in excess of the design objective, producing 61.5 M tonnes/yr of solid sodium cyanide and 2.1 M tonnes/yr of specialty potassium cyanide. This marginal overproduction was factored in to account for small amounts of alkali cyanides lost in components of the process not included in the process simulation.

Section 7: Critical to Quality Variables

Not Applicable for this report

Section 8: Product Concepts

Not Applicable for this report

Section 9: Superior Product Concepts

Not Applicable for this report

Section 10: Competitive Patent Analysis

Not Applicable for this report

Section 11: Preliminary Process Synthesis

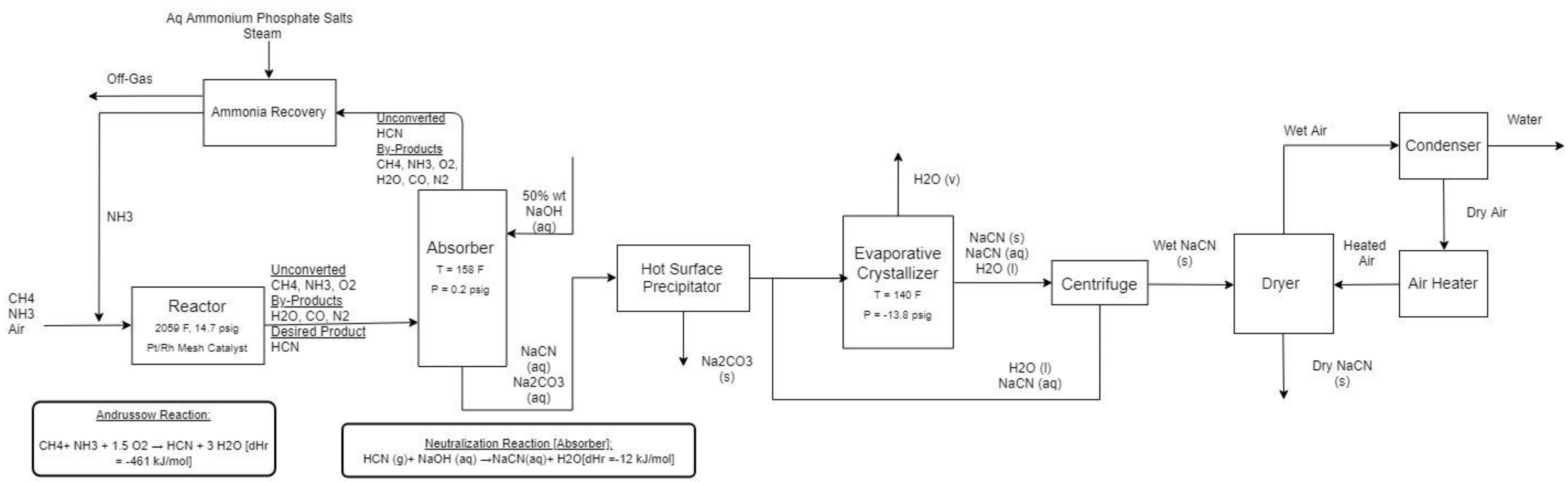

Figure 11.1. Block flow Diagram of Process

Section 11.2: HCN Production

Hydrogen Cyanide (HCN) is one of the main precursors in the production of NaCN and other alkali cyanides. The two main commercial manufacturing methods used to produce HCN are the Andrussow and BMA (Degussa) processes, represented by Equations 1 and 2 respectively.

1. $CH_4 + NH_3 + 1.5\ O_2 \rightarrow HCN + 3\ H_2O$, ΔH_R =-481.06 kJ/mol
2. $CH_4 + NH_3 \rightarrow HCN + 3\ H_2$, ΔH_R = 251 kJ/mol

Both reaction pathways have their respective advantages/disadvantages depending on the scale of manufacture and downstream requirements, so both were considered in our initial process design. Both processes use platinum based catalysis and co-produce hydrogen gas. The main difference between the two is that the Andrussow process utilizes air while Degussa does not. In addition, the Degussa process is reported to have higher conversion of ammonia to hydrogen cyanide compared to the Andrussow process, 80-87% vs 60-65%, respectively.[7] However, the Degussa process is strongly endothermic and requires a longer residence time in the reaction vessel, resulting in increased utility cost for sustaining the reaction and increases capital cost for a larger reaction vessel. The Andrussow process, once initiated, becomes self-sustaining resulting in essentially adiabatic operation. Based on these considerations we chose the Andrussow process. This decision is in line with current industry practices, as the Andrussow process provides for better process thermal efficiency and is better suited for high throughput production.[8]

[7] The Manufacture of Hydrocyanic Acid by the Andrussow Process, J.M. Pirie, 1958
[8] Encylopedia of Chemical Processing and Design: Volume 27-Hydrogen Cyanide pg.12

Section 11.3: Choice of Reactor Conditions

The Andrussow reaction mechanism is actually comprised of 13 simultaneous, sequential, and competing mechanistic steps. A complete optimization of the process over a range of temperature, pressures, and feed compositions is not available in open literature. Moreover, the complexity of the mechanism limited our ability to rigorously model this reaction.

The Andrussow reactor, composed of both the HCN producing reaction and the main side reactions, was modelled in ASPEN Plus using the RSTOICH reactor block. The reactions and respective conversions modelled in RSTOICH were based on industry standard compositions of byproducts/unconverted reactants in the effluent gas, presented in the Ullmann's Encyclopedia of Industrial Chemistry[9]. The reactor conditions reported for these outlet conditions were 2059°F and 14.7 psig, with a molar feed ratio of 1:1:1.3 for methane, ammonia, and oxygen. The design of the reactor itself, discussed in Section 16 with calculations in Appendix B.4, was based on a linear gas velocity and catalyst contact time from US20110171101A1, which presents a design for an industrial Andrussow reactor. [10]

Table 11.1 Reaction Conversions Utilized in RSTOICH Block

Reaction	Conversion	Based on
$CH_4 + H_2O \rightarrow CO + H_2$	35 %	CH_4
$4\ NH_3 + 3\ O_2 \rightarrow 2\ N_2 + 6\ H_2O$	22 %	NH_3
$CH_4 + 2\ O_2 \rightarrow 2\ H_2O + CO_2$	3.6 %	CH_4

[9] Cyano Compounds, Inorganic - 1.2.1. Andrussow Process. (2012). In *Ullmann's Encyclopedia of Industrial Chemistry*(Vol. 10, pp. 676-677). Weinheim: Wiley-VCH Verlag GmbH & KGaA.
[10] US20110171101A1, Schaefer, 2011

Flow rates for the reactor inlet were determined based on the production goal of 60 M Tonne/yr of sodium cyanide product and assuming high (99%) conversions in the downstream neutralization and crystallization processes, as well of 330 days/yr, 24 hr/day plant uptime.

Section 11.4: Ammonia Recovery

The outlet stream of the HCN reactor contains a significant amount of unreacted ammonia, close to 800 kg/hr, which without any design solution, would flow out of the process as part of the outlet residual vapor stream. This represented an obvious environmental and human health hazard which had to be addressed. Our first design solution involved the implementation of a flare stack, modeled by an RGIBBS reactor in ASPEN Plus, in which the residual vapor containing ammonia would be sent and burned, producing a mix of NOx, CO_2, CO, and H_2. This solved the immediate human-health hazard but still posed environmental emission risks and waste of valuable feedstock.

Next, we considered the possibility of recovery and recycle of this ammonia back to the feed of the reactor. A system was designed based on Patent US3718731A involving the absorption of ammonia by monoammonium phosphate to form diammonium phosphate and consequent stream stripping to regenerate the ammonia vapor.[11] The operation was able to recycle approximately 84.6% of the unreacted ammonia, lowering our required feed input of the material by 15.3%. This corresponds to a reduction in ammonia raw material feed costs of $1,941,000 per year. With an investment cost of approximately $1.3MM for the ammonia recovery operation, the payback period will be less than one year.

[11] US3718731A, Carlson, E I du Pont de Nemours and Co, 1973

Section 11.5: HCN Absorption

Impure hydrogen cyanide gas from the Andrussow reactor is fed to the caustic absorption column, in which both HCN and CO_2 will absorb and react in the caustic solution to form aqueous sodium cyanide and sodium carbonate. Following absorption, it was assumed that the reactions of HCN and CO_2 happened very quickly. Subsequently, it was assumed that the reactions of absorbed HCN and CO_2 were not mass transfer limited, as a high driving force for absorption would exist due to how quickly absorbed reactants would be converted to aqueous product. Therefore, because reaction kinetics and mass transfer were assumed to be quick, the conversion of absorbed CO_2 and HCN to aqueous product were modeled using equilibrium conditions in ASPEN Plus. Using ASPEN Plus, a 4.64 % molar excess of sodium hydroxide relative to hydrogen cyanide was determined, in order to achieve virtually complete (>99.9%) conversion of HCN to aqueous sodium cyanide, while accounting for the formation of sodium carbonate.

Section 11.6: Separations

The process design incorporates both vapor-liquid and solid-liquid separations. Vapor-liquid separations inherent in units such as the HCN neutralization absorber and evaporative sodium cyanide crystallizer were partially modelled in APSEN Plus and were designed based on required parameters and recommended operating conditions.

Using the required outlet flow rates and compositions from the neutralization absorber determined in ASPEN Plus, parameters including column sizing and tray determination required for the separation were calculated. The evaporative crystallizer was modeled in ASPEN Plus to determine the required evaporation rate and mass fraction of solids in the outlet slurry. In order to increase yield and keep the mass fractions of solids in the effluent slurry at a reasonably low percentage for flow, the saturated mother liquor separated from the downstream centrifuge was recycled back into the crystallizer. The implementation of this recycle stream increased the evaporative load on the crystallizer but resulted in a higher overall crystal throughput allowing us to reach our desired solids production goal without the use of an additional crystallizer unit. Additionally, the recycle stream lowered the mass fraction of solids in the outlet slurry from approximately 90% to 20% which is a reasonable percentage for flow.

Solid-liquid separation units including the hot surface precipitator and dryer are modeled outside of ASPEN Plus using various assumptions, discussed in the design of each relevant unit. The incorporation of sodium carbonate formation and its required separation were added to the ASPEN Plus simulation after a preliminary design was made. Although sodium carbonate is the primary impurity in the production of sodium cyanide, near complete separation is not required to reach desired product purity. A detailed discussion for the hot precipitator design can be found in Section 16.4, Equipment Descriptions, and design calculations can be found in Appendix B.4.

Several methods were initially considered in order to dry the solids product, including flash drying, fluidized bed drying, and spray drying. Based on the moisture content entering the dryer (~5%), it is assumed that a flash dryer using heated air will be the most applicable drying system for this application, as it allows for high rates of mass transfer and outlet moisture content within required purity conditions. Based on Patent US3197883A, a flash dryer for drying wet sodium cyanide solid uses air heated between 100 °C and 500 °C, preferably between 100 °C and 200 °C. This design utilizes hot air fed at 150 °C, and the dryer itself operates at relatively low temperature, preventing thermal degradation of the product.

Section 12: Assembly of Database

Section 12.1: Input Costs

The process to produce specialty cyanides requires ammonia, methane, air, and caustic soda as primary inputs. Our input material prices were determined by examining market reports, noting historical averages as well as recent fluctuations in price. To reduce variable costs, ambient air was used as the source of oxygen. The selling price of the final sodium cyanide product was taken to be $0.86 per pound, the median of a range provided by the project statement ($0.82 - $0.90 per pound).

Table 12.1 Summary of Input Costs to the Process

Raw Material	Price per Unit	Amount Required per op-year
Ammonia	$0.16/lb	67 MM lbs
NaOH	$0.16/lb	117 MM lbs
KOH	$0.23/lb	3.9 MM lbs
Methane (from Natural Gas)	$5.48/1000 SCF	1808 MM SCF

Section 12.2: ASPEN Simulation

Our process was primarily modeled in ASPEN Plus. Many of the streams within the process contain molecular species dissociated partially or completely into ions within a liquid solvent, which have the ability to precipitate out of solution as crystalline salts ($NaCN$, Na_2CO_3) under certain conditions. In order to properly model these interactions, electrolyte non-random two-liquid (ELECNRTL) was chosen as the main property method. The property method provides specialized thermodynamic models and parameters to represent the non-ideal behavior of liquid phase components. We utilized ASPEN Plus' electrolyte wizard tool to define the electrolyte components and select the relevant reactions among these components in the process streams.

Section 12.3: Safety and MSDS

This process utilizes and produces a variety of highly flammable, toxic, and hazardous components. MSDS sheets for relevant reagents and products within the process are listed in the Appendix C. Implementation of safety measures is discussed in Section 22.

Section 13: Process Flow Diagrams and Material Balances

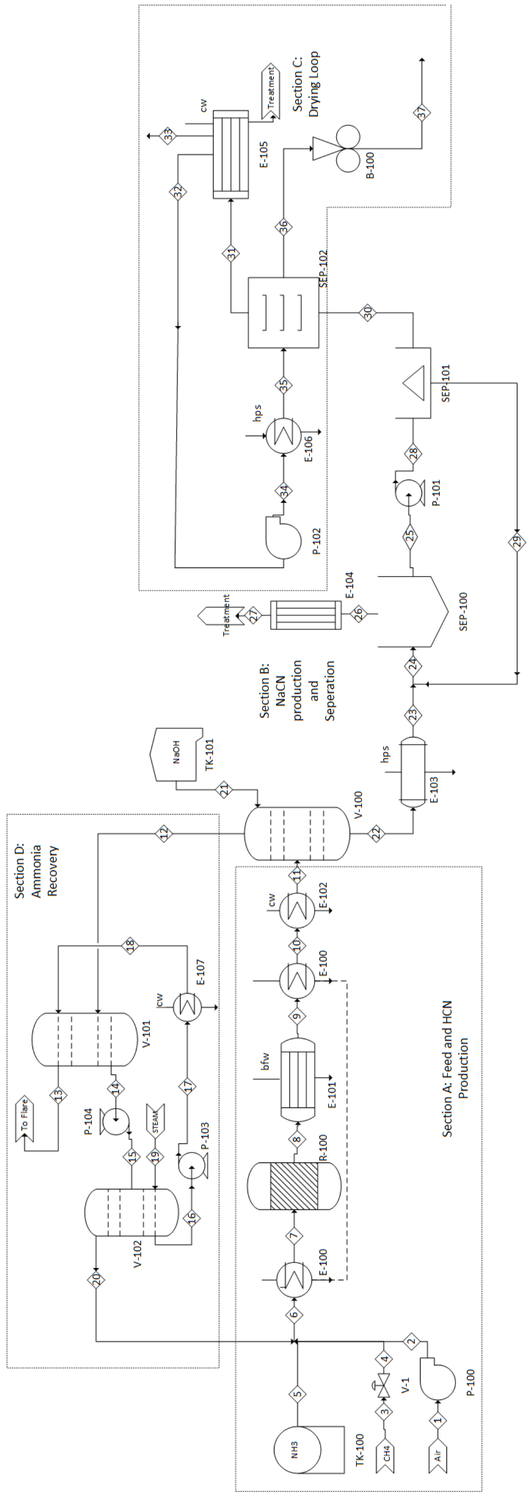

Figure 13.1. Overall Process Flow Diagram. Broken down into four main sections [A,B,C,D]

Section 13.2: Section A

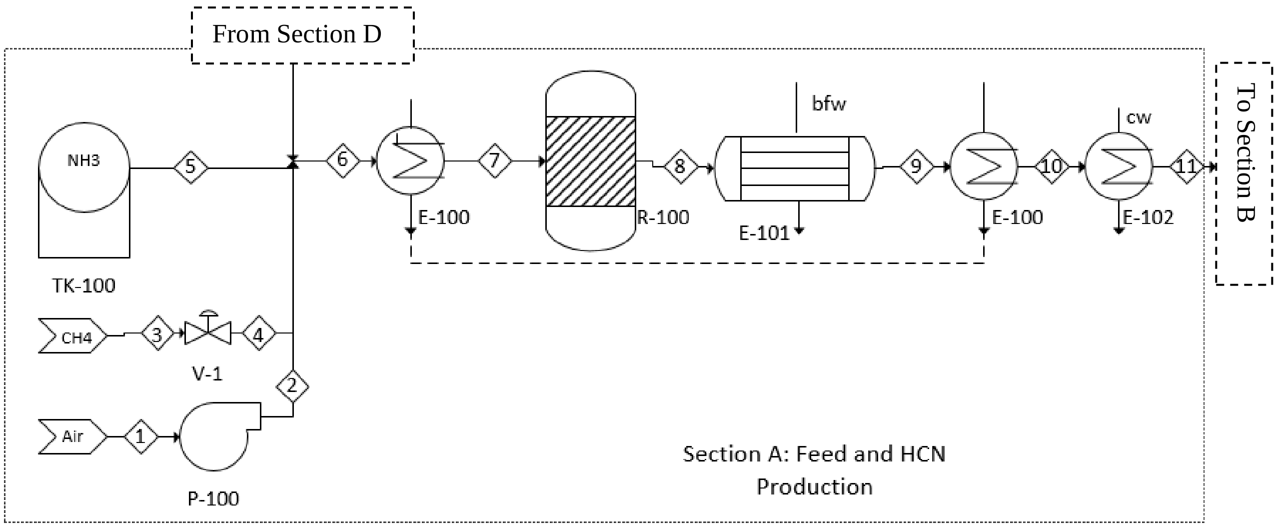

Figure 13.2. Process Flow Diagram Section A

Table 13.1 Section A Material Balance

Stream ID	1	2	3	4	5	6	7	8	9	10	11
Temperature (°F)	77	77	77	77	77	80	392	2058	600	324	158
Pressure (psig)	0	17.7	200	17.7	17.7	17.7	14.7	14.7	11.7	8.7	5.7
Vapor Fraction		1	1	1	1	1	1	1	1	1	1
Mass Flow (lbs/hr)	104528	104528	9478	9478	8448	125317	125317	125317	125317	125317	125317
Component Mass Flow											
CH4	-	-	9478	9478	-	9478	9478	179	179	179	179
NH3	-	-	-	-	8448	9980	9980	1796	1796	1796	1796
O2	24550	24550	-	-	-	24550	24550	3217	3217	3217	3217
N2	79978	79978	-	-	-	79978	79978	81783	81783	81783	81783
H2O	-	-	-	-	-	1329	1329	20857	20857	20857	20857
HCN	-	-	-	-	-	-	-	9503	9503	9503	9503
CO2	-	-	-	-	-	-	-	936	936	936	936
H2	-	-	-	-	-	-	-	1251	1251	1251	1251
CO	-	-	-	-	-	-	-	5793	5793	5793	5793
Molar Flow (lbmol/hr)	3622	3622	591	591	496	4873	4873	5495	5495	5495	5495

Section 13.3: Section B

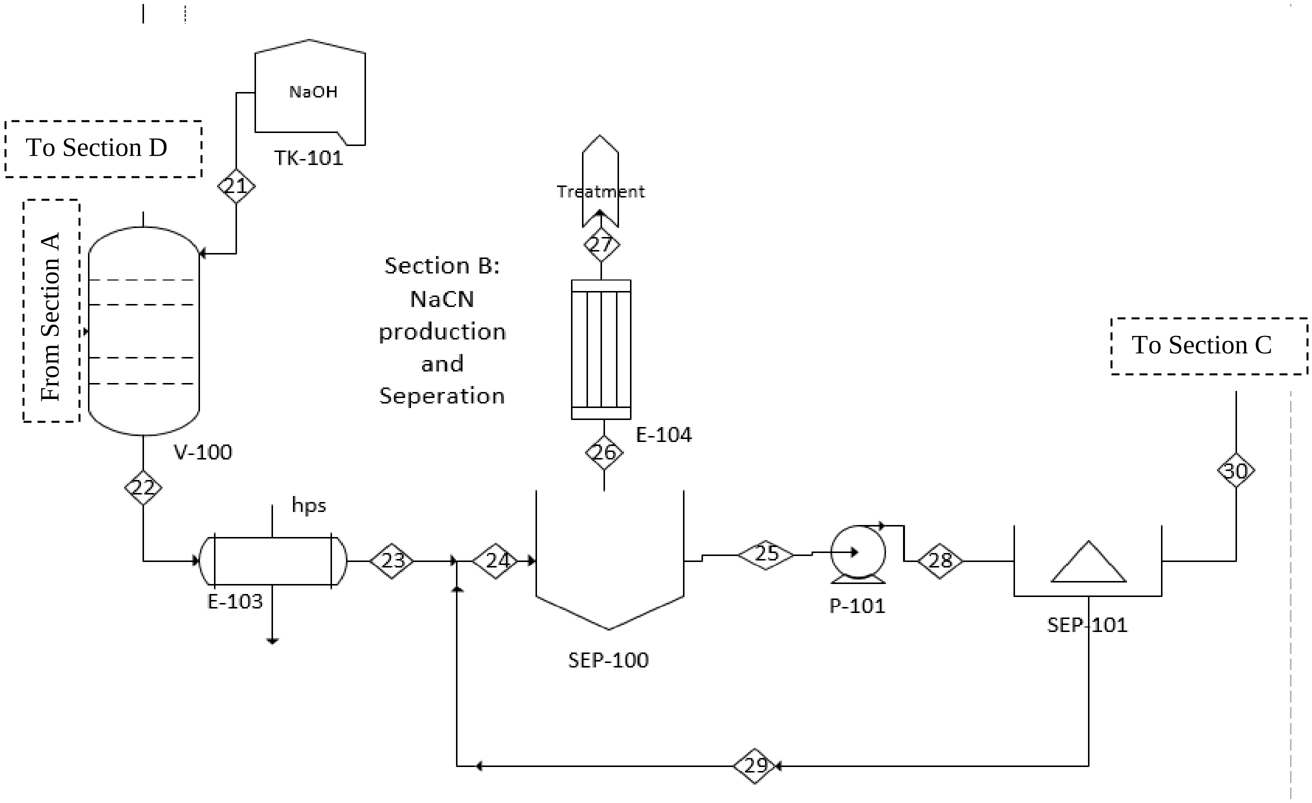

Figure 13.3. Process Flow Diagram Section B

Table 13.2. Section B Material Balance

Stream ID	21	22	23	24	25	26	27	28	29	30
Temperature (°F)	77	187	196	156	140	140	140	140	140	140
Pressure (psig)	0.2	0.2	0	0	-13.8	-13.8		0.2	0.2	0.2
Vapor Fraction	0	0	0	0	0	1	0	0	0	0
Mass Flow (lbs/hr)	29432	33677	33254	101731	86596	15135	15135	86596	68479	18117
Component Mass Flow										
NaCN (aq)	-	17199	17199	33991	16995	-	-	16995	16742	253
NaCN(s)	-	-	-	-	16975	-	-	16975	0	16975
Na2CO3 (aq)	-	530	106	518	419	-	-	419	412.06	6
Na2CO3(s)	-	-	-	-	99	-	-	99	-	99
NaHCO3(aq)	-	0.08	0.016	1	1	-	-	1	1	-
NaHCO3(s)	-	-	-	-	-	-	-	-	-	-
NaOH (aq)	14715	254	254	16911	16911	-	-	16911	16656.2	255
H2O	14715	15658	15658	50295	35163	15130	15130	35163	34633	530
NH3	-	4	4	4	-	4	4	-	-	-
HCN	-	0.1	0.1	0.1	-	0.28	0.28	-	-	-
Molar Flow (lbmol/hr)	1553	1600	1588	5040	3852	840	840	3852	3452	400

Section 13.4: Section C

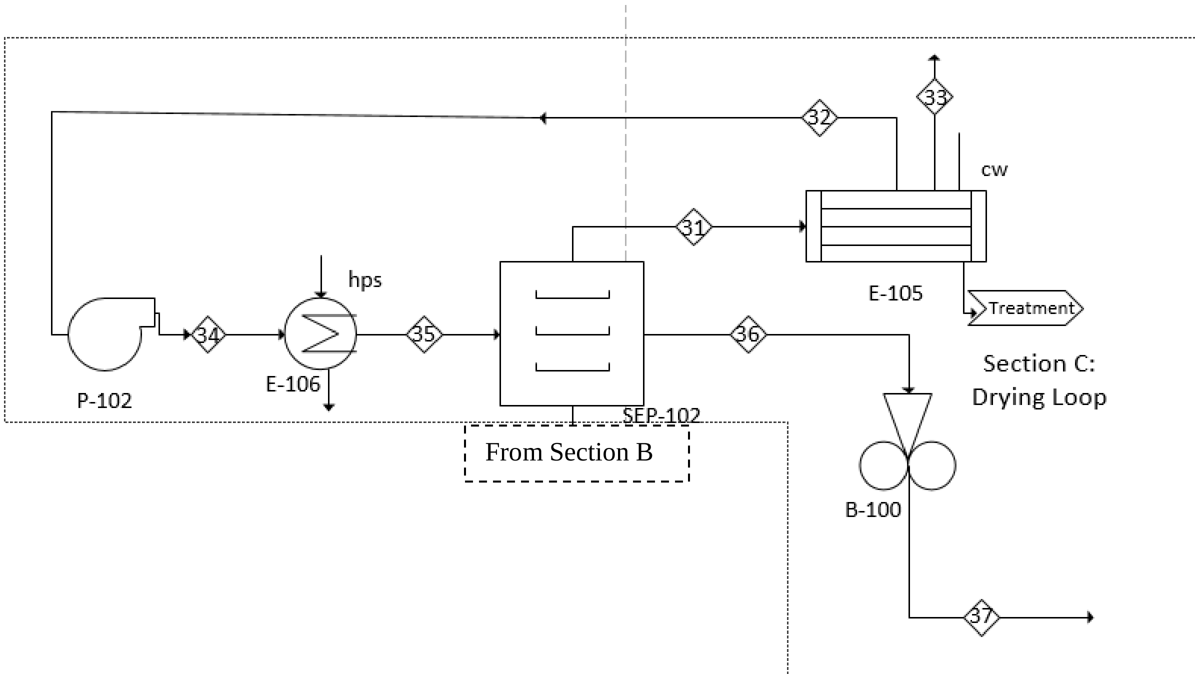

Figure 13.4. Process Flow Diagram Section C

Table 13.3. Section C Material Balance

Stream ID	31	32	33	34	35	36	37
Temperature (°F)	140	122	122	122	302	140	140
Pressure (psig)	3	0	0	6	3	0	0
Vapor Fraction	1	1	0	1	1	0	0
Mass Flow (lbs/hr)	22430	21958	472	21958	21958	17646	17646
Component Mass Flow							
NaCN (aq)	-	-	-	-	-	-	-
NaCN(s)	-	-	-	-	-	17230	17230
Na2CO3 (aq)	-	-	-	-	-	-	-
Na2CO3(s)	-	-	-	-	-	106	106
NaHCO3(aq)	-	-	-	-	-	-	-
NaHCO3(s)	-	-	-	-	-	-	-
NaOH (aq)	-	-	-	-	-	254	254
H2O	2015	1543	472	1543	1543	56	56
N2	15658	15658	-	15658	15658	-	-
O2	4756	4756	-	4756	4756	-	-
HCN	0.02	-	0.02	-	-	-	-
Molar Flow (lbmol/hr)	771	745	26	745	745	369	369

Section 13.5: Section D

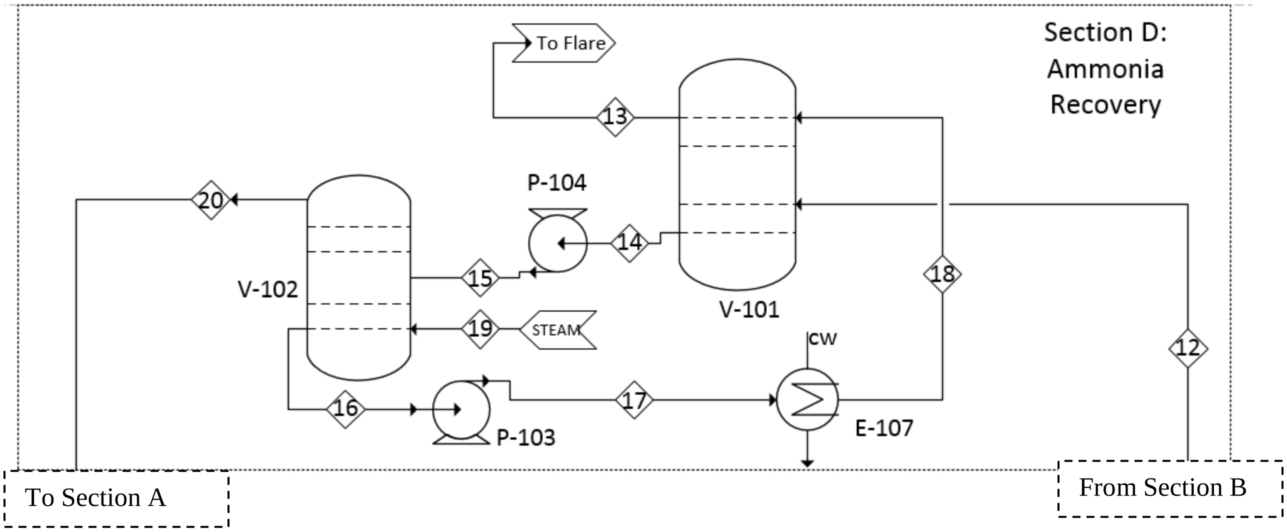

Figure 13.5. Process Flow Diagram Section D

Table 13.4. Section D Material Balance

Stream ID	12	13	14	15	16	17	18	19	20
Temperature (°F)	211	157	140	140	190	190	158	392	150
Pressure (psig)	0	0	0	25	0	25	22	15	0
Vapor Fraction	1	1	0	0	0	0	0	1	1
Mass Flow (lbs/hr)	121071	125113	21347	21347	23003	23003	23003	3968	2313
Component Mass Flow									
CH4	179	179	-	-	-	-	-	-	-
NH3	1792	242	2	2	18	18	18	-	1532
O2	3218	3218	-	-	-	-	-	-	-
N2	81784	81784	-	-	-	-	-	-	-
H2O	26339	31931	7117	7117	10306	10306	10306	3968	780
HCN	0.09	0.09	-	-	-	-	-	-	-
CO2	717	717	-	-	-	-	-	-	-
H2	1251	1251	-	-	-	-	-	-	-
CO	5793	5793	-	-	-	-	-	-	-
NH4+	-	-	3628	3628	1988	1988	1988	-	-
H2PO4-1	-	-	1874	1874	10691	10691	10691	-	-
HPO4-2	-	-	8724	8724	-	-	-	-	-
Molar Flow (lbmol/hr)	5441	5661	706	706	793	793	793	220	133

Section 14: Process Description

Section 14.1: Section A

Feed

A spherical anhydrous ammonia storage tank, TK-100, is employed to hold approximately 2 days worth of production requirement at 85% vessel volume capacity. The specification sheet for the ammonia feed storage tank can be found in Section 17. Ammonia is fed into the process at a rate of 8448 lbs/hr at 77°F and 17.7 psig. Natural gas located on-site is fed into the process at 200 psig. A high pressure gas regulator (V-100) reduces pressure to 17.7 psig. Ambient air is fed into the system via a centrifugal turbo blower, raising pressure to 17.7 psig at a mass flow rate of 104,528 lbs/hr. The vapor stream mixture, Stream 6, is preheated to 392°F via a process stream heat exchanger (E-100) which simultaneous cools Stream 9 from 600°F to 324°F. This process heat exchanger was employed to lower heating and cooling utility requirements.

HCN Synthesis

The first step in the process involves the production of HCN gas in reactor R-100, via the Andrussow process described in U. S. patents 1934838 and 1957749. The mixed inlet stream (Stream 7) contains methane, ammonia, and air, with molar ratios of methane to ammonia to oxygen at 1:1:1.3. The stream is fed into the reactor operating at 2058°F and 17.7 psig and flows downward through a pad of woven mesh screens lined with catalyst of 90% Platinum and 10% Rhodium with a cumulative thickness of 3 mm. The reaction gas flowing out (Stream 8) is comprised of the hydrogen cyanide product (about 7% by volume), unconverted ammonia and methane, by-products of carbon monoxide, hydrogen gas, water vapor, carbon dioxide, and a large proportion of nitrogen. To avoid decomposition of the hydrogen cyanide, the gas is quickly cooled from 2058°F to 600°F via a waste heat boiler (E-101) which generates 90,000 lbs/hr of

500 psig high pressure steam. Further cooling occurs via a process stream heat exchanger (E-101) to bring the vapor stream down to 324°F. An additional heat exchanger (E-102) employing cooling water as the heat transfer fluid is utilized to bring the process stream to the caustic absorber conditions at 158°F.

Section 14.2: Section B

HCN Absorption

Stream 11 is fed into an absorber (V-100) operating at atmospheric pressure and 158°F. Keeping the temperature low reduces the tendency for HCN to polymerize and minimizes decomposition of ammonia, which can result in a loss of yield as well as contamination of the NaCN product. Stream 21, comprised of a 50 wt% of aqueous sodium hydroxide, is fed from storage tank TK-101 into the column at a rate of 29,432 lbs/hr. An excess of NaOH, about 5% greater than stoichiometric requirements, is fed to prevent localized HCN polymerization and to account for the production on undesired by-products like sodium bicarbonate and sodium carbonate. The caustic solution flows counter-current to the vapor stream. Here a neutralization reaction occurs between the hydrogen cyanide and sodium hydroxide, forming aqueous sodium cyanide and water. The reaction is assumed to be fast and proceed to nearly 100% conversion within the column. The vapor stream exiting the absorption column is then sent to a series of absorption and stripping columns to recover the unreacted ammonia and recycle it back the feed of HCN reactor. The liquid effluent (Stream 22) exits the column at 186°F at a rate of 33,677 lbs/hr. The stream contains 51% by weight aqueous sodium cyanide, 1.6% by weight aqueous sodium carbonate (Na2CO3), 0.75% aqueous sodium hydroxide, and trace amounts of sodium bicarbonate (NaHCO3). The sodium carbonate is produced in the absorption process by the reaction of carbon dioxide by-product with NaOH.

Hot-Surface Precipitation and Crystallization

Stream 22 flows through a heat exchanger (E-103) which has a surface temperature of between 220°F and 250°F. The principal purpose of this unit is to provide a surface for which to selectively crystallize out the sodium carbonate impurity since its solubility is inversely proportional to temperature. A film of sodium carbonate is formed on the surface and is measured via pressure or temperature differential to determine when the efficiency of the surface has been decreased to the point of adversely affecting the process. This design solution was referenced from DuPont Patent US8894961B2, and is further described in Section 16. Based on surface area of 13,000 ft^2 and input from industrial consultants, the exchanger is assumed to remove approximately 80% of the incoming sodium carbonate and takes approximately 24 hours before the fouling compromises its efficiency and has to be switched out with its spare and washed using a high pressure water stream. Stream 23 leaves the hot surface exchanger at 196°F and is mixed with recycle stream 29 before entering a forced circulation evaporative crystallizer (SEP-100). The crystallizer unit operates at 140°F and -13.8 psig, conditions within a range recommended by Patent US2773752A. Hydrolysis and decomposition of sodium cyanide begins to occur at around 158°F so greater temperatures are not advised. Additionally, at temperatures lower than 100°F, sodium cyanide crystals tend to form hydrates which would not be desirable on the basis of final product purity. The crystallizer evaporates 15,135 lbs/hr of water which escapes the unit via Stream 26 which also contains trace amounts of ammonia and hydrogen cyanide vapor. The outlet vapor stream is then condensed and fed straight to effluent waste water treatment system where it is treated in three stages (primary, secondary, and tertiary) to remove the hazardous contaminants, which will be discussed further in Section 22. The heat duty required by the unit is 14.98 MMBTU/hr, which is supplied by the high pressure stream generated by the waste heat boiler. Approximately 16,975 lbs/hr of NaCN are crystallized out of solution and leave Stream 25 as a 20 wt % solids slurry.

Centrifugation

Stream 25 is pumped to 0.2 psig via a centrifugal pump (P-101) and fed into a pusher centrifuge (SEP-101) at 140°F. The centrifuge operates continuously and dewaters the crystal slurry to about a 5% moisture content as per the manufacturer's specifications. The mother liquor saturated with NaCN ions (Stream 29) is recycled back into the crystallizer. The wet cake (Stream 30) is then transported to a flash dryer unit (SEP-102) via a solids feeder.

Section 14.3: Section C

In the dryer, the wet material is dispersed into a stream of 38,396 lbs/hr of heated air (Stream 35) which flows into the unit at 302°F and 3 psig. Using the heat from the air stream, the solids dry as it is conveyed through the unit. The exhaust gas (Stream 31) exits the dryer at 140°F and relative humidity of 95% and is passed through two cyclones to entrain any NaCN dust or fines that may have be retained. The water vapor laden air stream then flows through a condenser (E-105), which cools the air stream to 122°F, bringing the humid air to its saturation point at a relative humidity 80%, condensing out 473 lbs/hr of water. A closed recycle loop of the air is employed for environmental remediation which prevents air containing microparticles of NaCN from leaving the process. In addition, the recycling of this exhaust gas also reduces the energy load imposed on the process heater (E-106) by approximately 65%. The solids leaving the dryer (Stream 36) are reduced to a moisture content of 0.3% on a mass basis. The solid NaCN content is approximately 97.7%, with the remaining mass comprised of impurities (0.6% Na2CO3, 1.0% NaOH).The solids are then sent to a briquetting press (B-100) at 17,644 lbs/hr in which solid briquettes are formed under high pressure, with dimensions of 1.8x1x1 in.

Section 14.4: Section D

Ammonia Recovery

The crude product gas containing unconverted ammonia exiting from the caustic absorber V-100 (Stream 12) is sent to tray column V-101 at 211°F and atmospheric pressure. This unit utilizes a monoammonium phosphate salt solution (Stream 15) to react with the ammonia to bring it into solution and produce diammonium phosphate. This reaction absorbs 1532 lbs/hr of ammonia into solution, which is 85.4% of the total ammonia entering the column. The diammonium phosphate solution (Stream 14) then undergoes a thermal reversal process in packed column V-102 via steam stripping (Stream 16) to liberate ammonia back into the vapor phase. This process regenerates the monoammonium phosphate, which is then recycled back to column V-101 for continued usage and the stripped ammonia stream (Stream 17) is sent back to the reactor inlet to offset feed ammonia requirements.

Section 14.5: Specialty Cyanide Production

Potassium cyanide production process will be carried out in an analogous fashion to that of the sodium cyanide, utilizing the same equipment and processing steps. Instead of an aqueous solution of sodium hydroxide, potassium hydroxide will be fed to the caustic absorber (V-100) to produce aqueous potassium cyanide.

Section 15: Utility Requirements

To keep the process as efficient as possible, energy sinks and sources were identified in order to determine the optimal heat integration strategy. The process generates significant heat in the HCN Reactor (R-100) which is extracted in the waste heat boiler to generate almost 90,000 lbs of high pressure (500 psig) steam. The latent heat provided by condensing this steam makes it so that we do not have to purchase any utilities to heat any of the process streams. The net utility of steam produced in this process after utilization for heating is approximately 70,000 lb/hr, as seen in Table 15.2. The bulk of the generated steam being used is for the evaporative crystallizer (SEP-100), as large amounts of water must be vaporized to crystallize out product.

All heat exchangers involving cooling water were designed to allow the cooling water to rise from 90°F to 120°F. Cooling water in this process either serves to reduce temperature of a stream, or to condense water content out of a vapor stream. The bulk of the cooling water utility is used for the latter function, specifically to condense the vapor leaving the crystallizer so it can be sent to liquid waste treatment, as seen in Table 15.3. In total, the process uses no outside energy for heating, 572,000 lbs/hr cooling water, 90,000 lbs/hr boiler feed water, and 1847 kWh of electricity.

An internal process heat exchanger was designed (E-100) in order to minimize utility requirements. In this unit, stream 6 was pre-heated to 392°F, the required inlet temperature to the Andrussow reactor, by flowing it counter-current with the vapor effluent (stream 9) from the reactor's waste-heat boiler (E-101). The waste heat boiler does not cool the vapor product of the Andrussow reaction (stream 8) to a low enough temperature appropriate to feed to the caustic absorber, so this internal heat exchanger also serves to cool waste heat boiler vapor effluent down from 601°F to 324°F. This corresponds to 11.6 MM BTU/hr of heat transfer between the two streams.

Table 15.1: Electricity Requirements

Utlitily	Unit ID	Description	Quantity/hr
Electricity (kWh)			
	P-100	Inlet Air Blower	1426
	P-101	Slurry Pump	8
	P-102	Dryer Air Blower	145
	SEP-101	Pusher Centrifuge	75
	B-100	Briquetter	65
	P-103	Ammonia Pump1	1
	P-104	Ammonia Pump2	1
Net Utility (kWh)			1847

Table 15.2 Steam Production/Utilization

Utility	Unit ID	Description	Heat Duty (BTU/hr)	HPS Steam Required(lbs/hr)
High Pressure Steam				
	E-103	Hot Surface Prec	134234	179
	E-106	Dryer Heater	370378	493
	SEP-100	Crystallizer	14977000	19916
Total			15481612	20587
Total Produced			-	(89,852)
Net Utility (lb)				(69,265)

Table 15.3: Cooling Water Utilization

Utility	Unit ID	Description	Heat Duty (BTU/hr)	CW Required (lbs/hr)
Cooling Water				
	E-102	R-100 Effluent Cooler	-678613	22620
	E-104	Crystallizer Condenser	-15991233	533041
	E-105	Dryer Air Condenser	-588026	19601
	E-107	V-102 Effluent Cooler	-250996	8367
Net			-17508868	583629

Table 15.4: Boiler Feed Water Utilization

Utility	Unit ID	Desctiption	(BTU/hr)	BFW Required (/hr)
Boiler Feed Water				
	E-101	Waste Heat Boiler	67528740	89852
Net			67528740	89852

Table 15.5: Low Pressure Steam Utilization

Utility	Unit ID	Description	LPS Required (/hr)
Low Pressure Steam			
	V-102	Ammonia Stripper	3960
Net			3960

Table 15.6: Utility Summary

Utility	Unit	Ratio (per lb CN product)
Cooling Water	lb	34.0
High Pressure Steam	lb	4.0
Low Pressure Steam	lb	0.2
Boiler Feed Water	lb	5.2
Electricity	kWh	0.1

Section 16: Equipment and Unit Descriptions

Section 16.1: Storage Tanks

Ammonia Storage

Unit ID: TK-100	Temperature: 77°F
Type: Spherical Storage Tank	Pressure: 200 psig
Material: Stainless Steel	Diameter: 29.6 ft
Specification Sheet: Section 17, pg. 74	

This storage tank was designed to hold approximately 2.5 rail cars worth raw material assuming an average rail car capacity of 34,500 gal so that a rail car can be unloaded whenever the tank gets half full. This corresponds to approximately 2 days worth of material based on the plants productions requirements. The total storage volume is 101,470 gallons (13,564 ft^3) which accounts for a volumetric safety factor of 1.17 so that tank operates at a maximum of 85% of its total volumetric capacity. This smaller volumetric capacity was chosen primarily for the safety of the plant's and mine's employees, such that in the case of a failure an exorbitant amount of material will not be released (recommended by industrial consultants). A spherical configuration comprised of stainless steel was chosen in order to provide an even distribution of stresses on the surface of the tank, both internally and externally, to minimize chances of structural failure.

NaOH Storage

Unit ID: TK-002	Temperature: 77°F
Type: Conical Roof Storage Tank	Pressure: 0.2 psig
Material: Carbon Steel	Height: 43 ft
Specification Sheet: Section 17, pg. 75	Diameter: 43 ft

This storage tank was designed to hold approximately 7 days worth of raw material based on process production requirements. The tank is a conical roof storage vessel with a low pressure. The total storage volume is 59,053 ft, accounting for a volumetric safety factor of 1.17 so that the tank operates at a maximum of 85% of its total volumetric capacity. Carbon steel was chosen as material of construction based on its low material cost compared to alternatives.

Section 16.2: Reaction Vessels

HCN Andrussow Reactor

Unit ID: R-100

Type: Reactor

Material: Stainless Steel 316

Specification Sheet: Section 17, pg. 76

Temperature: 2059°F

Pressure: 14.7 psig

Height: 17 ft

Diameter: 10.4 ft

This reactor was designed based on the industry standard Andrussow process for the production of HCN gas. Based on a process production requirement for volumetric flow rate, and a linear gas velocity of 16.4 ft/s recommended by Patent 2011/171101, a diameter of 10.4 feet was determined. Using a H/D ratio of 1.4, within a range recommended by Patent 2011/171101, a height of 14.6 ft was determined. The vessel is composed of small section of Pt-Rh catalyst gauze at which the reaction takes place, with the remaining empty volume being devoted to a waste heat boiler, which is discussed in Section 16.4. Using a 16.4 ft/s linear gas velocity and a contact time of 0.0006 s recommended by Patent 2011/171101, a gauze thickness of 3 mm was determined. This corresponds to 40 layers of 0.076 mm standard thickness gauze, which is within industry standards.

Caustic Absorber

Unit ID: R-101	Temperature: 158°F
Type: Absorber	Pressure: 0.2 psig
Material: 304 Stainless Steel	Height: 86.5 ft
Specification Sheet: Section 17, pg. 83	Diameter: 5.1 ft

This vessel was designed to absorb 99.99% of the incoming HCN gas produced by reactor R-100. This required 14.5 theoretical stages, calculated using a modified Kremser equation shown in the Appendix B.2. Assuming a plate efficiency of 30%, the total number of trays required in the tower was determined to be 49. A tower height of 86.5 ft was determined using a tray spacing of 1.5 ft with additional 14 ft of height to account for vapor-liquid disengagement and surge sump. Single pass sieve trays were chosen based on Figure 13.5 of Seider et al. 304 Stainless Steel was recommended as material of construction of both the tower and plates due to its excellent corrosion resistance.

Ammonia Recovery Absorber

Unit ID: V-101

Type: Absorber

Material: 304 Stainless Steel

Specification Sheet: Section 17, pg. 84

Temperature: 158°F

Pressure: 0.2 psig

Height: 68 ft

Diameter: 4.7 ft

This vessel was designed to absorb 84.6% of the incoming NH_3 gas in the vapor outlet from absorber V-100. This required 10.8 theoretical stages, calculated using a modified Kremser equation shown in the Appendix B.2 .Assuming a plate efficiency of 30%, the total number of trays required in the tower was determined to be 36. A tower height of 68 ft was determined using a tray spacing of 1.5 ft with additional 14 ft of height to account for vapor-liquid disengagement and surge sump. Single pass sieve trays were chosen based on Figure 13.5 of Seider et al.[12] 304 Stainless Steel was recommended as material of construction of both the tower and plates due to its excellent corrosion resistance.

[12] Seider, W.D., J.D. Seader, D.R. Lewin, and S. Widago, "Product and Process Design Principles", John Wiley & Sons., New Jersey, 2017, pg.394

Ammonia Recovery Stripper

Unit ID:V-102

Type: Stripper

Material: 304 Stainless Steel

Specification Sheet: Section 17, pg. 85

Temperature: 194°F

Pressure: 0.2 psig

Height: 41 ft

Diameter: 4 ft

This vessel was designed to absorb 99.99% of the incoming NH_3 that was absorbed in column V-101. This required 5.4 theoretical stages, calculated using a modified Kremser equation shown in the Appendix B.2. Assuming a plate efficiency of 30%, the total number of trays required in the tower was determined to be 18. A tower height of 41 ft was determined using a tray spacing of 1.5 ft with additional 14 ft of height to account for vapor-liquid disengagement and surge sump. Single pass sieve trays were chosen based on Figure 13.5 of Seider et al.[13] 304 Stainless Steel was recommended as material of construction of both the tower and plates due to its excellent corrosion resistance.

[13] Seider, W.D., J.D. Seader, D.R. Lewin, and S. Widago, "Product and Process Design Principles", John Wiley & Sons., New Jersey, 2017, pg.394

Section 16.3: Pumps and Blowers

Feed Air Blower

Unit ID: P-100	Temperature: 140°F
Type: Centrifugal Turbo Blower	Inlet Pressure: 0 psig
Material: Cast Iron	Outlet Pressure: 14.7 psig
Specification Sheet: N/A	Consumed Power: 3419 hp

The air blower was designed to feed 23,647 ft^3 of ambient air into the process at over two times atmospheric pressure. Cast iron was chosen as it was the cheapest option.

Slurry Pump

Unit ID: P-101	Temperature: 140°F
Type: Centrifugal Pump	Inlet Pressure: -13.66 psig
Material: Stainless Steel	Outlet Pressure: 0.2 psig
Specification Sheet: Section 17, pg. 87	Consumed Power: 8.5 hp

This pump was designed to raise the pressure of the slurry exiting the low pressure evaporative crystallizer to slightly over atmospheric pressure and to maintain a flow 200 gpm. A head of 82.7 ft and pump efficiency of 0.62 was determined in ASPEN. Guidelines of Seider et al. suggest a single stage centrifugal pump in Vertical Split Case (VSC) orientation with shaft rpm of 1800 and max motor hp of 200. Due to the presence of free hydroxides present in the slurry, stainless steel construction material was chosen.

Dryer Air Blower

Unit ID: P-102

Type: Centrifugal Turbo Blower

Material: Cast Iron

Specification Sheet: N/A

Temperature: 122°F

Inlet Pressure: 0 psig

Outlet Pressure: 9 psig

Consumed Power: 194 hp

This blower was designed to raise the pressure of the cool wet air exiting the dryer air condenser at a capacity of 5,610 ft^3/min. A pressure increase of 9 psi was determined to account for assumed pressure drops of 3 psi across the flash dryer, dryer air condenser, and dryer air heater.

Ammonia Recovery Pump 1

Unit ID: P-103	Temperature: 160F
Type: Centrifugal Pump	Inlet Pressure: 0 psig
Material: Stainless Steel	Outlet Pressure: 25 psig
Specification Sheet: N/A	Consumed Power: 0.61 hp

This pump was designed to raise the pressure of the liquid exiting tower V-101 and to maintain a flow of 66.29 gpm. A head of 40.67 ft and pump efficiency of 0.62 was determined in ASPEN. Guidelines[14] of Seider et al. suggest a single stage centrifugal pump in Vertical Split Case (VSC) orientation with shaft rpm of 1800 and max motor hp of 200. Due to the presence of dissolved ammonium phosphate salt, stainless steel construction material was chosen.

[14] Seider, W.D.,J.D. Seader, D.R. Lewin, and S. Widage, "Product and Process Design Principles", John Wiley & Sons Inc., New Jersey, 20178, pg 452

Ammonia Recovery Pump 2

Unit ID: P-104	Temperature: 160F
Type: Centrifugal Pump	Inlet Pressure: 0 psig
Material: Stainless Steel	Outlet Pressure: 25 psig
Specification Sheet: N/A.	Consumed Power: 0.89 hp

This pump was designed to raise the pressure of the liquid exiting tower V-102 and to maintain a flow of 53.77 gpm. A head of 40 ft and pump efficiency of 0.62 was determined in ASPEN. Guidelines[15] of Seider et al. suggest a single stage centrifugal pump in Vertical Split Case (VSC) orientation with shaft rpm of 1800 and max motor hp of 200. Due to the presence of dissolved ammonium phosphate salt, stainless steel construction material was chosen.

[15] Seider, W.D.,J.D. Seader, D.R. Lewin, and S. Widage, "Product and Process Design Principles", John Wiley & Sons Inc., New Jersey, 20178, pg 452

Section 16.4: Process Heat Exchangers

Reactor Waste Heat Boiler

Unit ID: E-101

Type: Counter Current Heat Exchanger

Material: Stainless Steel 316

Specification Sheet: Section 17, pg. 77

Process Temp. Change:

Area: 33,529 ft^2

Heat Exchanged: 68.2 MM BTU/hr

The reactor waste heat boiler was designed with the aid of ASPEN Exchanger Design and Rating (EDR) in accordance with TEMA standards. Unit E-101 was designed to cool R-100 effluent from 2059°F to 572°F using cooling water as the heat transfer fluid. This exchanger is comprised of 1 shell with a diameter of 10.4 ft and 15,606 tubes with single pass each with an inner diameter of 0.75 in. and length 13 ft. The calculated heat transfer coefficient is 7.08 BTU/hr*ft^2°F. This unit is located within the housing provided by reactor R-100, approximately 2 ft after the gas passes through the catalyst gauze pad. It produces 90,000 lbs/hr of high pressure steam.

Process Feed Pre-Heater/ Secondary Cooler Reactor Outlet

Unit ID: E-102	LMTD: 226°F
Type: Counter Current Heat Exchanger	Area: 5144 ft^2
Material: Carbon Steel	Heat Exchanged: 11.6 MM Btu/hr
Specification Sheet: Section 17, pg. 78	Pressure: 14.7 psig

This counter current shell and tube heat exchanger unit was designed to simultaneously preheat the feed to reactor R-100 to 392°F and cool the effluent gas from the waste heat boiler E-101 from 600.8°F to 324°F. The area of 5144 ft^2 was determined by assuming a heat transfer coefficient of 10 Btu/(hr-ft^2-°F), recommended in Table 12.5 of Seider et. al for an air/air system. Carbon steel was selected based on being the lowest cost material.

Hot Surface Precipitator

Unit ID: E-103	LMTD: 268 °F
Type: Counter Current Heat Exchanger	Area: 13004 ft^2
Material: Stainless Steel	Heat Exchanged: 134234 Btu/hr
Specification Sheet: Section 17, pg. 80	Pressure: 500 psig

This counter current shell and tube heat exchanger unit was designed to precipitate 80% of the aqueous sodium carbonate impurity formed in the caustic absorber. This percentage removal was determined in order to produce a final solid sodium cyanide product that was within the desired purity range, while also minimizing the amount of sodium carbonate that must be precipitated out. An area of heat transfer based on the inner diameter of the tubes was determined by assuming the unit must be switched out every 24 hours, corresponding to a sodium carbonate build-up of 1 mm thickness on the inside of the tubes. The bottoms product of the caustic absorber serves as the inlet at a temperature of 187°F. This inlet temperature is within the desired temperature range of 122-302°F required for the surface in order to precipitate out sodium carbonate, recommended by Patent WO2010135733A1. The shell contains saturated high pressure steam, which condenses to provide latent heat to the tubes, slightly increasing the temperature of the tubes by 5°C. This temperature change was recommended by industry consultants, in order to provide a boundary layer for sodium carbonate precipitation on the inner surface of the tubes that is at a higher temperature than the bulk fluid. Stainless steel was selected for material as opposed to carbon steel due to ease of maintenance, which this unit will often require.

Dryer Air Condenser

Unit ID: E-105 | LMTD: 25.5°F

Type: Counter-Current Heat Exchanger | Area: 461 ft^2

Material: Carbon Steel | Heat Exchanged: 370378 Btu/hr

Specification Sheet: Section 17, pg. 82 | Pressure: 0 psig

This counter-current shell-and-tube heat exchanger is designed to condense liquid water out of a 95% relative humidity air stream at 140°F and 3 psig. Water will condense out at atmospheric pressure inside the unit, with the resulting air stream being saturated with water at 122°F and atmospheric pressure. The heat exchange required for this temperature will be supplied by cooling water at 90°F, which will exit the exchanger at 120°F. The area required for heat transfer was determined using a heat transfer coefficient of 50 Btu/(hr-°F-ft^2) recommended in Table 12.5 of Seider et. al. for air/water systems. Carbon steel was selected based on being the lowest cost material.

Dryer Air Heater

Unit ID: E-106	LMTD: 237°F
Type: Counter-Current Heat Exchanger	Area: 156.48 ft^2
Material: Carbon Steel	Heat Exchanged: 370378 Btu/hr
Specification Sheet: N/A	Pressure: 500 psig

This counter-current shell-and-tube heat exchanger is designed to increase the temperature of 122°F air fully saturated with water to 302°F. The heat exchange required for this temperature will be supplied by 500 psig steam. The area required for heat transfer was determined using a heat transfer coefficient of 10 Btu/(hr-°F-ft^2), recommended by Table 12.5 in Seider et. al. for air/air systems. Carbon steel was selected based on being the lowest cost material.

Ammonia Loop Cooler

Unit ID: E-107

Type: Counter-Current Heat Exchanger

Material: Carbon Steel

Specification Sheet: N/A

LMTD: 82.86°F

Area: 61 ft^2

Heat Exchanged: 250,996 BTU/hr

Pressure: 0 psig

This counter-current shell-and-tube heat exchanger is designed to cool a stream of ammonium phosphate solution to 158°F at 0 psig. The heat exchange required for this temperature will be supplied by cooling water at 90°F, which will exit the exchanger at 120°F. The area required for heat transfer was determined using a heat transfer coefficient of 50 Btu/(hr-°F-ft^2) recommended in Table 12.5 of Seider et. al. 2017 for air/water systems.[16] Carbon steel was selected based on being the lowest cost material.

[16] Seider, W.D., J.D. Seader, D.R. Lewin, and S. Widago, "Product and Process Design Principles", John Wiley & Sons., New Jersey, 2017, pg. 376

Section 16.5: Solid Liquid Separation Units

Evaporative Crystallizer

Unit ID: SEP-100	Temperature: 140°F
Type: Forced Circulation	Pressure: -13.66 psig
Material: Carbon Steel	Height: 22 ft
Specification Sheet: Section 17, pg. 86	Diameter: 15 ft

The evaporative crystallizer was sized using a residence time of 1.8 hours recommended from Patent US4083935A. To meet hourly production requirements and form solid crystals of appropriate size. Based on inlet volumetric flow of 2,034 ft^3/hr, a total vessel volume of 3,661 ft^3 was calculated. A height to diameter ratio of 1.5 was recommended by industrial consultants in order to give the dimensions highlighted above. The crystallizer produces approximately lbs/hr of sodium cyanide crystals via the evaporation of 15,134 lbs/hr of water. The unit requires a heat duty of 14.9 MMBTU/hr which is satisfied by supplying the vessel with approximately 20,000 lbs/hr of high pressure steam.

Centrifuge

Unit ID: SEP-101 | Temperature: 140°F

Type: Pusher, B&P S-900 Model | Pressure: 0.2 psig

Material: 304/316 Stainless Steel | Consumed Power: 100 hp

Specification Sheet: Section 17, pg. 88

Since the dewatering efficiencies of centrifuges highly depend on capacity, inlet solids weight percentage, crystal size, and mechanical configuration, various external manufactures were contacted to handle our process' specific requirements. The S-900 pusher centrifuge model manufactured by B&P Littleford was selected for this process on the basis of its large nominal capacity (45 mtph), high dewatering efficiency (wet cake moisture content of 5%), and mechanical integrity. The unit is 135 inches long, 102 inches wide, 70 inches tall, and weighs 17,400 lbs. The centrifuge processes 86,586 lbs/hr of slurry material, forming a wet cake with 5% moisture.

Wet Cake Dryer

Unit ID: SEP-102 | Temperature: 140°F
Type: Flash Dryer | Pressure: 3 psig
Material: Stainless Steel | Evaporation Rate: 471.8 lbs/hr
Specification Sheet: Section 17, pg. 90

This unit was modelled to operate at slightly above ambient pressure at 3 psig and a temperature of 140°F. Further pilot scale testing is required to determine kinetic data of evaporation for this vessel, in order to determine the complete design for this unit. The dryer was designed outside of ASPEN Plus, assuming the heated air stream (302°F) used to dry the wet cake will have fast uptake of moisture, before being cooled to the dryer's ambient temperature of 140°F. Because of this assumption, it was assumed that the cooled, humid air would exit the dryer at a high relative humidity of 95%, allowing for less energy intensive condensation to remove the excess water uptake. The condenser to remove the excess water intake and subsequent air heater were designed in ASPEN, allowing for a continuous recycle of air in the drying process. Rudimentary costing for this unit was determined using an equation found in Table 16.32 of Seider et. al, which was dependent on the evaporation rate of 471.8 lbs/hr and using stainless steel as the material.

Briquetter

Unit ID: SEP-103

Type: Roller Press Briquetter

Material: Stainless Steel

Specification Sheet: Section 17, pg. 89

Temperature: 140°F

Max Pressing Force: 3610 psig

Consumed Power: 87.4 hp

The Roller Press ARP-5 manufactured by ACAN was selected to compact the sodium cyanide crystals into their final briquetted form with dimensions of 1.80x1.80x1 in with a throughput of 17,644 lbs/hr. The units occupies 54 ft^2 of floor area and requires a power supply of 87.4 hp.

Section 17: Specification Sheets

Ammonia Storage Tank

Identification:	**Item**	*Ammonia Storage Tank*	Date: *17 April 2018*
	Item No.	TK-100	By:
	No. required	1	
Function: Store excess ammonia.			
Operation: Continuous			
Materials handled:		To Process	
Temperature (°F)		77	
Pressure (psig)		200	
Vapor fraction		1	
Mass flow (lb/hr)		8448	
Molar flow (lbmol/hr)		496	
Component Mass Flow (lb/hr)			
Methane		0	
Ammonia		8448	
Carbon Dioxide		0	
Hydrogen Cyanide		0	
Carbon Monoxide		0	
Hydrogen		0	
Oxygen		0	
Nitrogen		0	
Water		0	
Design Data:			
	Amount (time) of Ammonia Stored: 2.1 days Diameter: 29.6 ft Material of Construction: Stainless Steel Design: Spherical Storage Tank Pressure: 200 psig Total Storage Volume: 13,564 ft^3; 101470 gallons		
Comments and drawings: See Section 12			

NaOH Storage Tank

Identification:	**Item**	*NaOH Storage Tank*	Date: *17 April 2018*
	Item No.	TK-101	By:
	No. required	1	

Function: Store 50% by weight caustic soda

Operation: Continuous

Materials handled:	To Process
Temperature (°F)	77
Pressure (psig)	0.2
Vapor fraction	0
Mass flow (lb/hr)	29432
Molar flow (lbmol/hr)	1553
Component Mass Flow (lb/hr)	
NaCN (aq)	0
NaCN (s)	0
Na2CO3 (aq)	0
Na2CO3 (s)	0
NaHCO3 (aq)	0
NaOH (aq)	14715
H2O	14715
NH3	0
HCN	0

Design Data:

Amount (time) of Caustic Stored: 7 days
Height: 43 ft
Diameter: 43 ft
Material of Construction: Carbon Steel
Design: Cone Roof Storage Tank
Pressure: 0.2 psig
Total Storage Volume: 59,053 ft^3; 441,747 gallons

Comments and Drawings: See Section 13, Section B

HCN Andrussow Reactor

Identification:	**Item**	*Dehydrocyclization Reactor*	Date: *17 April 2018*
	Item No.	R-100	By:
	No. required	1	

Function:

Operation: Continuous

Materials handled:	Overall Feed	Overall Effluent
Temperature (°F)	392	2059
Pressure (psig)	14.7	14.7
Vapor fraction	1	1
Mass flow (lb/hr)	125317	125317
Molar flow (lbmol/hr)	4873	5495
Component Mass Flow (lb/hr)		
Methane	9478	179
Ammonia	9980	1796
Oxygen	24550	3217
Nitrogen	79978	81783
Water	1329	20857
Hydrogen Cyanide	0	9503
Carbon Dioxide	0	936
Hydrogen	0	1251
Carbon Monoxide	0	5793

Design Data:

Mass catalyst/unit: 434.3 lb
Material of Construction:
Height/unit: 17 ft
Total Reactor Volume: 40,234 ft^3
Total Reactor Pressure Drop: 0 psig
Orientation: Vertical
Superficial Fluid Velocity: 16.4 ft/s
Catalyst Contact Time: 0.0006 min

Utilities: Adiabatic due to exothermic reaction sustaining high temperature

Comments and Drawings: See Section 13, Section A

Waste Heat Boiler

Identification:	**Item**	*Waste Heat Boiler*	Date: *17 April 2018*	
	Item No.	E-101	By:	
	No. required	1		
Function: Cool reactor effluent product stream				
Operation: Continuous				
Materials handled:	Cold In	Cold Out	Hot In	Hot Out
Temperature (°F)	469.8	469.8	2059	600.8
Pressure (psig)	500	500	14.7	11.7
Vapor fraction	0	1	1	1
Mass flow (lb/hr)	90769	90769	125317	125317
Molar flow (lbmol/hr)	-	-	2492.26	2492.26
Component Mass Flow (lb/hr)				
Methane	0	0	179	179
Ammonia	0	0	1796	1796
Oxygen	0	0	3217	3217
Nitrogen	0	0	81783	81783
Water	90769	90769	20857	20857
Hydrogen Cyanide	0	0	9503	9503
Carbon Dioxide	0	0	936	936
Hydrogen	0	0	1251	1251
Carbon Monoxide	0	0	5793	5793

Design Data:

Type: Shell-in-Tube, Fixed Head
Effective Surface Area: 33,529.7 ft^2
LMTD: 602.3
Heat Exchanged: 68,218,300 BTU/hr
Heat Transfer Coeff: 7.08 BTU/(hr*ft^2*°F)
Tube Side Material of Construction: SS 316
Shell Side Material of Construction: SS 316
No. Tubes/Pass: 15606
Tube Length: 13 ft
No. of Tube Passes: 1
Baffle Spacing: 25 in
Shell Diameter: 10.8

Utilities: 90769 lb/hr of boiler feed water

Comments and Drawings: See Section 13, Section A

Process to Process Exchanger

Identification:	**Item**	*Process-Process Exchanger*	Date: *17 April 2018*	
	Item No.	E-100	By:	
	No. required	1		
Function: Cool reactor effluent product stream				
Operation: Continuous				
Materials handled:	Cold In	Cold Out	Hot In	Hot Out
Temperature (°F)	80	392	2059	600.8
Pressure (psig)	17.7	14.7	14.7	11.7
Vapor fraction	1	1	1	1
Mass flow (lb/hr)	125317	125317	125317	125317
Molar flow (lbmol/hr)	-	-	2492.26	2492.26
Component Mass Flow (lb/hr)				
Methane	9478	9478	179	179
Ammonia	9980	9980	1796	1796
Oxygen	24550	24550	3217	3217
Nitrogen	79978	79978	81783	81783
Water	1329	1329	20857	20857
Hydrogen Cyanide	0	0	9503	9503
Carbon Dioxide	0	0	936	936
Hydrogen	0	0	1251	1251
Carbon Monoxide	0	0	5793	5793

Design Data:

Type: Shell-in-Tube, Fixed Head
Effective Surface Area: 5144 ft^2
LMTD: 226.31
Heat Exchanged: 11,641,200 BTU/hr
Heat Transfer Coeff: 10 BTU/(hr*ft^2*°F)
Tube Side Material of Construction: Carbon Steel
Shell Side Material of Construction: Carbon Steel
Tube Length: 16 ft

Utilities: See Section 15

Comments and Drawings: See Section 13, Section A

Secondary Reactor Effluent Cooler

Identification:	**Item**	*Secondary Reactor Effluent Cooler*	Date: *17 April 2018*
	Item No.	E-102	By:
	No. required	1	

Function: Further cool reactor effluent product stream to inlet absorber conditions

Operation: Continuous

Materials handled:	Cold In	Cold Out	Hot In	Hot Out
Temperature (°F)	90	120	324	158
Pressure (psig)	3	0	8.7	0.2
Vapor fraction	0	0	1	1
Mass flow (lb/hr)	22620	22620	125317	125317
Molar flow (lbmol/hr)	1277	1277		
Component Mass Flow (lb/hr)			179	179
Methane	0	0	1796	1796
Ammonia	0	0	3217	3217
Oxygen	0	0	81783	81783
Nitrogen	0	0	20857	20857
Water	22620	22620	9503	9503
Hydrogen Cyanide	0	0	936	936
Carbon Dioxide	0	0	1251	1251
Hydrogen	0	0	5793	5793
Carbon Monoxide	0	0	5495	5495

Design Data:

Type: Shell-in-Tube, Fixed Head
Effective Surface Area: 109 ft^2
LMTD: 123.81
Heat Exchanged: 678613 BTU/hr
Heat Transfer Coeff: 50 BTU/(hr*ft^2*°F)
Tube Side Material of Construction: Carbon Steel
Shell Side Material of Construction: Carbon Steel
Tube length: 12 ft

Utilities: 22620 lbs/hr of cooling water

Comments and drawings: See Section 13, Section A

Hot Surface Precipitator

Identification:	**Item**	*Hot Surface Precipitator*	Date: *17 April 2018*
	Item No.	E-103	By:
	No. required	2	

Function: Precipitate out solid sodium carbonate impurity

Operation: Continuous

Materials handled:	Cold In	Cold Out	Buildup	Hot In	Hot Out
Temperature (°F)	187	196	-	469.8	469.8
Pressure (psig)	0.2	0	-	500	500
Vapor fraction	0	0	-	1	0
Mass flow (lb/hr)	33677	33254	423	178.5	178.5
Molar flow (lbmol/hr)	1600	1588	12		
Component Mass Flow (lb/hr)					
NaCN (aq)	17199	17199	0	0	0
NaCN(s)	0	0	0	0	0
Na2CO3 (aq)	530	106	424	0	0
Na2CO3(s)	0	0	0	0	0
NaHCO3(aq)	0.08	0.016	0.064	0	0
NaHCO3(s)	0	0	0	0	0
NaOH (aq)	254	254	0	0	0
H2O	15658	15658	0	178.5	178.5
NH3	4	4	0	0	0
HCN	0.1	0.1	0	0	0

Design Data:

Type: Shell-in-Tube, Fixed Head
Effective Surface Area: 13004 ft^2
Heat Exchanged: 134234 BTU/hr
Fouling Thickness: 0.001 mm
Unit Replacement/Maintenance: every 16hr
Tube Side Material of Construction: Carbon Steel
Shell Side Material of Construction: Carbon Steel
Tube length: 20 ft

Utilities: 178.5 lbs/hr of high pressure steam

Comments and drawings: See Section 13, Section B

Crystallizer Condenser

Identification:	**Item**	*Crystallizer Condenser*	Date: *17 April 2018*
	Item No.	E-104	By:
	No. required	1	

Function: Condense the vapor outlet of the evaporative crystallizer

Operation: Continuous

Materials handled:	Cold In	Cold Out	Hot In	Hot Out
Temperature (°F)	90	120	140	140
Pressure (psig)	3	0	-13.8	-13.8
Vapor fraction	0	0	1	0
Mass flow (lb/hr)	533041	22620	15135	15135
Molar flow (lbmol/hr)	30093	30093	840	840
Component Mass Flow (lb/hr)				
Methane	0	0	0	0
Ammonia	0	0	4	4
Oxygen	0	0	0	0
Nitrogen	0	0	0	0
Water	533041	533041	15130	15130
Hydrogen Cyanide	0	0	0.28	0.28
Carbon Dioxide	0	0	0	0
Hydrogen	0	0	0	0
Carbon Monoxide	0	0	0	0

Design Data:

Type: Shell-in-Tube, Fixed Head
Effective Surface Area: 24174 ft^2
LMTD: 13.23
Heat Exchanged: 15991233 BTU/hr
Heat Transfer Coeff: 50 BTU/(hr*ft^2*°F)
Tube Side Material of Construction: Carbon Steel
Shell Side Material of Construction: Carbon Steel
Tube length: 20 ft

Utilities: 533041 lbs/hr of cooling water

Comments and drawings: See Section 13, Section B

Dryer Air Condenser

Identification:	**Item**	*Dryer Air Condenser*	Date: *17 April 2018*
	Item No.	E-105	By:
	No. required	1	

Function: Condense and remove excess vapor from the drying loop

Operation: Continuous

Materials handled:	Air In	Air Out	Water Out
Temperature (°F)	140	122	122
Pressure (psig)	3	0	0
Vapor fraction	1	1	0
Mass flow (lb/hr)	22430	21958	472
Molar flow (lbmol/hr)	771	745	26
Component Mass Flow (lb/hr)			
Methane	0	0	0
Ammonia	0	0	0
Oxygen	4756	4756	0
Nitrogen	15658	15658	0
Water	2015	533041	472
Hydrogen Cyanide	0.02	0	0.2
Carbon Dioxide	0	0	0
Hydrogen	0	0	0
Carbon Monoxide	0	0	0

Design Data:

Type: Shell-in-Tube, Fixed Head
Effective Surface Area: 462 ft^2
LMTD: 25.5
Heat Exchanged: 588026 BTU/hr
Heat Transfer Coeff: 50 BTU/(hr*ft^2*°F)
Tube Side Material of Construction: Carbon Steel
Shell Side Material of Construction: Carbon Steel
Tube length: 16 ft

Utilities: 533041 lbs/hr of cooling water

Comments and drawings: See Section 13, Section B

Caustic Absorber

Identification:	**Item**	*Caustic Absorber*	Date: *17 April 2018*
	Item No.	V-100	By:
	No. required	1	

Function: Neutralization reaction to form aqueous sodium cyanide

Operation: Continuous

Materials handled:	Liquid In	Liquid Out		Vapor In	Vapor Out
Temperature (°F)	77	187		158	211
Pressure (psig)	0.2	0.2		0	0
Vapor fraction	0	0		1	1
Mass flow (lb/hr)	29432	33677		125317	121071
Molar flow (lbmol/hr)	1553	1600		5495	5441
Component Mass Flow (lb/hr)					
NaCN (aq)	0	17199			
NaCN(s)	0	0	CH4	179	179
Na2CO3 (aq)	0	0	O2	3217	3217
Na2CO3(s)	0	0	N2	81783	81734
NaHCO3(aq)	0	0.08	CO2	936	717
NaHCO3(s)	0	0	CO	5793	5793
NaOH (aq)	14715	254	H2	1251	1251
H2O	14715	15658	H2O	20857	26339
NH3	0	4	NH3	1796	1792
HCN	0	0.1	HCN	9503	0.09

Design Data:

Pressure: 0 psig
Temperature: 158°F
Diameter: 5.1 ft
Height: 86.5 ft
Material of Construction: 304 Stainless Steel
Tray Type: Single Pass Sieve
Average Tray Efficiency: 0.30
Tray Spacing: 1.5 ft

Utilities: Adiabatic Operation

Comments and drawings: See Section 13, Section B

Ammonia Recovery Absorber

Identification:	**Item**	*NH3 Recovery Absorber*	Date: *17 April 2018*
	Item No.	V-101	By:
	No. required	1	

Function: Neutralization reaction to store ammonia as aqueous diammonium phosphate

Operation: Continuous

Materials handled:	Liquid In	Liquid Out		Vapor In	Vapor Out
Temperature (°F)	158	140		211	158
Pressure (psig)	22	0		0	0
Vapor fraction	0	0		1	1
Mass flow (lb/hr)	23003	21347		121071	125113
Molar flow (lbmol/hr)	793	706		5441	5661
Component Mass Flow (lb/hr)					
H20	10306	7117	CH4	179	179
O2	0	0	NH3	1792	242
CH4	0	0	O2	3218	3218
NH3	18	2	N2	81784	81784
HCN	0	0	H2O	26339	31931
NH4+	1988	3628	HCN	0.09	0.09
H2PO4-	10691	1874	CO2	717	717
HPO4--	0	8724	H2	1251	1251
			CO	5793	5793

Design Data:

Pressure: 0
Temperature: 158°F
Diameter: 4.7 ft
Height: 68 ft
Material of Construction: 304 Stainless Steel
Tray Type: Single Pass Sieve
Average Tray Efficiency: 0.30
Tray Spacing: 1.5 ft

Utilities: Adiabatic Operation

Comments and drawings: See Section 13, Section D

Ammonia Recovery Stripper

Identification:	**Item**	*NH3 Recovery Stripper*	Date: *17 April 2018*
	Item No.	V-102	By:
	No. required	1	

Function: Neutralization reaction to store ammonia as aqueous diammonium phosphate

Operation: Continuous

Materials handled:	Liquid In	Liquid Out		Vapor In	Vapor Out
Temperature (°F)	140	190		392	150
Pressure (psig)	25	0		15	0
Vapor fraction	0	0		1	1
Mass flow (lb/hr)	21347	23003		3968	2313
Molar flow (lbmol/hr)	706	793		220	133
Component Mass Flow (lb/hr)					
H20	7117	10306	CH4	3968	780
O2	0	0	NH3	0	1532
CH4	0	0	O2	0	0
NH3	2	18	N2	0	0
HCN	0	0	H2O	0	0
NH4+	3628	1988	HCN	0	0
H2PO4-	1874	10691	CO2	0	0
HPO4--	8724	0	H2	0	0
			CO	0	0

Design Data:

Pressure: 0 psig
Temperature: 158°F
Diameter: 4 ft
Height: 41 ft
Material of Construction: 304 Stainless Steel
Tray Type: Single Pass Sieve
Average Tray Efficiency: 0.30
Tray Spacing: 1.5 ft

Utilities: Adiabatic Operation

Comments and drawings: See Section 13, Section D

Evaporative Crystallizer

Identification:	**Item**	*Evaporative Crystallizer*	Date: *17 April 2018*
	Item No.	SEP-100	By:
	No. required	1	

Function:

Operation: Continuous

Materials handled:	Overall Feed	Vapor Out	Slurry Out
Temperature (°F)	156	140	140
Pressure (psig)	0	-13.8	-13.8
Vapor fraction	0	1	0
Mass flow (lb/hr)	101731	15135	86596
Molar flow (lbmol/hr)	5040	840	3852
Component Mass Flow (lb/hr)			
NaCN (aq)	33991	0	16995
NaCN(s)	0	0	16975
Na2CO3 (aq)	518	0	419
Na2CO3(s)	0	0	99
NaHCO3(aq)	1	0	1
NaHCO3(s)	0	0	0
NaOH (aq)	16911	0	16911
H2O	50295	15130	35165
NH3	4	4	0
HCN	0.1	0.28	0

Design Data:

Material of Construction: Carbon Steel
Height: 21.9 ft
Diameter: 14.6 ft
Total Reactor Volume: 3661.2 ft^3
Orientation: Vertical
Residence Time: 1.80 hrs

Utilities: 19916 lbs/hr of high pressure steam

Comments and drawings: See Section 13, Section B

Slurry Pump

Identification:	**Item**	*Slurry Pump*	Date: *17 April 2018*
	Item No.	P-101	By:
	No. required	1	

Function: Pump slurry from crystallizer to centrifuge

Operation: Continuous

Materials handled:	Slurry In	Slurry Out
Temperature (°F)	140	140
Pressure (psig)	-13.8	0.2
Vapor fraction	0	0
Mass flow (lb/hr)	86596	86596
Molar flow (lbmol/hr)	3852	3852
Component Mass Flow (lb/hr)		
NaCN (aq)	16995	16995
NaCN(s)	16975	16975
Na2CO3 (aq)	419	419
Na2CO3(s)	99	99
NaHCO3(aq)	1	1
NaHCO3(s)	0	0
NaOH (aq)	16911	16911
H2O	35165	35165
NH3	0	0
HCN	0	0

Design Data:

Material of Construction: Stainless Steel
Shaft rpm:1800
Type: Centrifugal
Orientation: VSC
Flowrate: 200 gpm
Head: 82.7 ft
Max Motor hp: 200

Utilities: 8.46 kWh of electricity

Comments and drawings: See Section 13, Section B

Pusher Centrifuge

Identification:	**Item**	*Pusher Centrifuge*	Date: *17 April 2018*	
	Item No.	SEP-101	By:	
	No. required	1		

Function: Separate NaCN crystals from mother liquor

Operation: Continuous

Materials handled:	Slurry In	Filter Cake	Mother Liquor
Temperature (°F)	140	140	140
Pressure (psig)	0.2	0.2	0.2
Vapor fraction	0	0	0
Mass flow (lb/hr)	86596	18117	68479
Molar flow (lbmol/hr)	3852	400	3452
Component Mass Flow (lb/hr)			
NaCN (aq)	16995	253	16742
NaCN(s)	16975	16975	0
Na2CO3 (aq)	419	6	412.06
Na2CO3(s)	99	99	0
NaHCO3(aq)	1	0	1
NaHCO3(s)	0	0	0
NaOH (aq)	16911	255	16656.2
H2O	35165	704.2	34460.8
NH3	0	0	0
HCN	0	0	0

Design Data:

Manufacturer: B&P Littleford
Nominal Capacity: 45 mtph
Construction Material: 304/316 Stainless Steel
Weight: 17,400 lbs
Motor Requirements: 100 hp
Dimensions (LxWxH) = 135x102x70 in

Utilities: 75 kWh of electricity

Comments and drawings: See Section 13, Section B

Briquetter

Identification:	**Item**	*Briquetter*	Date: *17 April 2018*
	Item No.	B-100	By:
	No. required	1	

Function: Compress dried solid into final compacted form

Operation: Continuous

Materials handled:	Dried Solids
Temperature (°F)	140
Pressure (psig)	0
Vapor fraction	0
Mass flow (lb/hr)	17644
Molar flow (lbmol/hr)	371
Component Mass Flow (lb/hr)	
NaCN (aq)	0
NaCN(s)	17230
Na2CO3 (aq)	0
Na2CO3(s)	106
NaHCO3(aq)	0
NaHCO3(s)	0
NaOH (aq)	254
H2O	54

Design Data:

Manufacturer: Acan
Occupied Floor Area: 5 m^2
Pressing Force: 3625 psig
Dimensions of Formed Briquette: 1.8x1.8x1in

Utilities: 65.2 kWh of electricity

Comments and drawings: See Section 13, Section C

Wet Cake Dryer

Identification:	**Item**	*Wet Cake Dryer*	Date: *17 April 2018*	
	Item No.	SEP-102	By:	
	No. required	1		

Function: Remove moisture from wet cake product

Operation: Continuous

Materials handled:	Wet Solid	Dry Solid	Air In	Air Out
Temperature (°F)	140	140	302	140
Pressure (psig)	0.2	0	3	0.2
Vapor fraction	0	0	1	1
Mass flow (lb/hr)	18117	17646	21958	22430
Molar flow (lbmol/hr)	400	369	745	771
Component Mass Flow (lb/hr)				
NaCN (aq)	253	0	0	0
NaCN(s)	16975	17230	0	0
Na2CO3 (aq)	6	0	0	0
Na2CO3(s)	99	106	0	0
NaHCO3(aq)	0	0	0	0
NaHCO3(s)	0	0	0	0
NaOH (aq)	255	254	0	0
H2O	530	56	1543	2015
N2	0	0	15658	15658
O2	0	0	4756	4756
HCN	0	0	0	0.02

Design Data:

Evaporation Rate: 472 lb/hr
Outlet Relative Humidity: 95%
Material: Stainless Steel
Type: Flash

Utilities: N/A

Comments and drawings: See Section 13, Section C

Section 18: Equipment Cost Summary

Table 18.1 Equipment Costing Summary

Process Equipment ID	Type	Purchase Cost	Bare Module Factor	Bare Module Cost
P-100	Process Machinery	$462,618	2.15	$994,629
P-101	Process Machinery	$14,543	3.30	$47,992
P-102	Process Machinery	$74,085	2.15	$159,283
P-103	Process Machinery	$14,562	3.30	$48,055
P-104	Process Machinery	$14,993	3.30	$59,477
TK-100	Storage	$894,212	3.05	$2,727,347
TK-101	Storage	$208,555	3.21	$669,461
E-100	Fabricated Equipment	$50,084	3.17	$158,766
E-101	Fabricated Equipment	$875,648	3.17	$2,775,803
E-102	Fabricated Equipment	$12,225	3.17	$38,753
E-103A	Fabricated Equipment	$489,806	3.17	$1,552,685
E-103B	Spares	$489,806	3.17	$1,552,685
E-104	Fabricated Equipment	$14,047	3.17	$44,529
E-105	Fabricated Equipment	$15,037	3.17	$47,667
E-106	Fabricated Equipment	$14,047	3.17	$44,529
E-107	Fabricated Equipment	$14,062	3.17	$44,577
SEP-100	Fabricated Equipment	$777,077	2.06	$1,600,779
SEP-101	Fabricated Equipment	$700,000	2.03	$1,421,000
SEP-102	Fabricated Equipment	$255,068	2.06	$525,440
V-100	Fabricated Equipment	$334,995	4.16	$1,393,579
V-101	Fabricated Equipment	$172,468	4.16	$717,470
V-102	Fabricated Equipment	$83,329	4.16	$346,647
R-100	Fabricated Equipment	$164,503	4.16	$684,332
B-100	Process Machinery	$176,793	2.30	$406,624
W-100	Process Machinery	$901,718	1.00	$901,718

Unit Costing Considerations

Pumps, Blowers, and Turbines

The costs for the pumps, blowers, and turbines were determined using the equations found in Chapter 16 of Seider et. al, 2017. Purchase cost calculations for the blowers were performed using the inlet volumetric flow rate and pressure change over the units, with these values being derived from ASPEN Plus simulations. The pump costing calculations required the same data, in addition to a calculated head for each unit. Specific values used for the costing calculations can be found in the stream results corresponding to each unit.

Heat Exchangers, Condensers, and Precipitator

The costs for the heat exchangers, Dryer Air Condenser, and the Hot Surface Precipitator were determined using surface area of heat transfer and material, which are discussed in Section 16. Costing calculations are performed using equations in Chapter 16 of Seider et. al, 2017. The Waste-Heat Boiler was designed and costed using the heat exchanger TEMA tool in ASPEN Plus.

Reactor Vessel

The reactor vessel R-100 was costed based on the size/shape and material, which is discussed in Section 16. Calculations used for the vessel are based on equations in Chapter 16 of Seider et. al, 2017, for a vertical pressure vessel.

Absorption and Stripping Columns

The columns are costed based on their size/shape and material selection, both of which are discussed in Section 16. Calculations used for costing are based on equations in Chapter 16 of Seider et. al, 2017, for vertical pressure vessels.

Storage Tanks

The storage tanks are costed based on size/shape and material selection, discussed in Section 16. Calculations for costing are based on equations in Chapter 16 of Seider et. al, 2017.

Evaporative Crystallizer and Flash Dryer

The Evaporative Crystallizer was costed based on the solid product production rate in tons/day, with a material basis of carbon steel. This calculation was performed using equations found in Chapter 16 of Seider et. al, 2017. Unfortunately, pilot scale testing of the drying system is outside the scope of this report, so the design cannot be rigorously modeled. Thus, costing for a flash drying unit was assumed to be largely based on the evaporation rate of water, so a costing equation for a flash drying unit based on evaporation rate was adapted from Chapter 16 of Seider et. al 2017.

Waste Treatment

Estimates for wastewater treatment costs were based on equations in Chapter 16 of Seider et. al, 2017 and using volumetric flow of processed material (gpm) as main input parameter. Primary, secondary, and tertiary treatment was recommended as treatment solutions considering the hazardous nature of contaminants present including ammonia and hydrogen cyanide.

Section 19. Fixed-Capital Investment

The total capital investment for the project was calculated using the costing variable relationships outlined below in Table 19.1 with information taken from Seider et. al, 2017. The bare-module costs for all fabricated equipment, process machinery, spares, and storage tanks can be found in the Equipment Costing Summary in Section 18. The total equipment purchase cost was calculated to be $7,221,136 and the total bare-module cost was found to be $18,954,650.

Table 19.1 Elements that comprise Total Capital Investment (*Seider et. al, 2017)*

Total bare-module costs for fabricated equipment	C_{FE}					
Total bare-module costs for process machinery	C_{PM}					
Total bare-module costs for spares	C_{spare}					
Total bare-module costs for storage and surge tanks	$C_{storage}$					
Total cost for initial catalyst charges	$C_{catalyst}$					
Total bare-module costs for computers and software, including distributed control systems, instruments, and alarms	C_{comp}					
Total bare-module investment, TBM		C_{TBM}				
Cost of site preparation		C_{site}				
Cost of service facilities		C_{serv}				
Allocated costs for utility plants and related facilities		C_{alloc}				
Total of direct permanent investment, DPI			C_{DPI}			
Cost of contingencies and contractor's fee			C_{cont}			
Total depreciable capital, TDC				C_{TDC}		
Cost of land				C_{land}		
Cost of royalties				C_{royal}		
Cost of plant startup				$C_{startup}$		
Total permanent investment, TPI					C_{TPI}	
Working capital					C_{WC}	
Total capital investment, TCI						C_{TCI}

The applicable components that are required to determine the Total Permanent Investment and their relationships to other components of Total Capital Investment can be found in Table 19.2. The cost of service facilities was increased to 10% of Total Bare Module Cost to account for more sensitive control and monitoring systems due to the presence of hydrogen cyanide in the system.

Table 19.2. Breakdown of Additional Costing Factors (*Seider et. al, 2017*)

Component Total Capital Investment	Relationship to other Costing Factors
Cost of Site Preparation	20% of Total Bare Module Cost
Cost of Service Facilities	10% of Total Bare Module Cost
Cost of Contingencies and Contractor's Fee	18% of Direct Permanent Investment
Cost of Land	2% of Total Depreciable Capital
Cost of Plant Startup	10% of Total Depreciable Capital

In addition to the high purchase price for all equipment, large costs will be incurred through the construction and setup of the plant itself. A summation of these costs with the overall bare-module cost for all equipment can be found below in Table 19.3, prepared using a spreadsheet assembled by Brian K. Downey using costing strategies from Seider et. al, 2017. The necessary Total Permanent Investment for this project will be $30.9 million dollars to construct and start up the plant.

Table 19.3. Components of Total Permanent Investment

Investment Summary				
Total Bare Module Costs:				
Fabricated Equipment	$	11,494,911		
Process Machinery	$	2,510,245		
Spares	$	1,552,685		
Storage	$	3,396,808		
Other Equipment	$	-		
Catalysts	$	-		
Computers, Software, Etc.	$	-		
Total Bare Module Costs:			$	18,954,650
Direct Permanent Investment				
Cost of Site Preparations:	$	3,790,930		
Cost of Service Facilities:	$	1,895,465		
Allocated Costs for utility plants and related facilities:	$	-		
Direct Permanent Investment			$	24,641,045
Total Depreciable Capital				
Cost of Contingencies & Contractor Fees	$	4,435,388		
Total Depreciable Capital			$	29,076,433
Total Permanent Investment				
Cost of Land:	$	581,529		
Cost of Royalties:	$	0		
Cost of Plant Start-Up:	$	2,907,643		
Total Permanent Investment - Unadjusted			$	32,565,605
Site Factor				0.95
Total Permanent Investment			$	30,937,324

To obtain the overall Total Capital Investment for the project, Working Capital must be accounted for and then added to the calculated cost for the Total Permanent Investment. The calculation of the project's Working Capital can be found in Table 19.4 and the project's Total Capital Investment comes out at $35.6 million. The Working Capital accounts for 30 days worth of accounts receivable, cash reserves, and accounts payable in addition to 4 days of sodium cyanide inventory and 2 days worth of stockpiled raw materials.

Table 19.4. Components of Working Capital for the project

Working Capital							
		2019		**2020**		**2021**
Accounts Receivable	$	3,994,521	$	1,997,260	$	1,997,260
Cash Reserves	$	420,193	$	210,097	$	210,097
Accounts Payable	$	(2,097,550)	$	(1,048,775)	$	(1,048,775)
Sodium Cyanide Inventory	$	532,603	$	266,301	$	266,301
Raw Materials	$	136,243	$	68,122	$	68,122
Total	**$**	**2,986,010**	**$**	**1,493,005**	**$**	**1,493,005**
Present Value at 15%	*$*	*2,596,531*	*$*	*1,128,926*	*$*	*981,675*
Total Capital Investment			**$**	**35,644,457**		

Section 20: Operating Costs

Section 20.1: Variable Costs

Table 20.1 Estimated Cost and Requirements of Raw Materials

Raw Material	Estimated Cost ($/lb)	Annual Requirement (lb)	Total Yearly Cost ($)
Methane (natural gas)	$0.14	79MM	$11.0MM
Ammonia	$0.16	67MM	$10.5MM
Sodium Hydroxide	$0.16	117MM	$18.1MM
Potassium Hydroxide	$0.23	3.9MM	$0.87MM
Monoammonium Phosphate	$0.25	0.8MM	$0.22MM
Pt-Rh Catalyst	$1.6M	869	$14.2MM
Total	-	-	$54.9MM

The methane used in the process is sourced from natural gas, which has a methane molar percentage between 87 and 97 percent[17]. As such, it was assumed that natural gas purchased would be acquired at an average of 92% molar percent methane, with the remaining percentage points representing heavier hydrocarbons, like ethane and propane. The value used for costing was $5.48 per 1000 standard cubic feet of natural gas for industrial use, obtained from the Energy Information Administration's profile on energy in Nevada for November of 2017[18].

Costing data for the ammonia feedstock was taken from Fertecon Agribusiness Intelligence's February 2018 report on ammonia[19]. The sodium hydroxide costing data was

[17] Chemical Composition of Natural Gas. (n.d.). Retrieved from https://www.uniongas.com/about-us/about-natural-gas/chemical-composition-of-natural-gas
[18]Nevada Natural Gas Prices. (n.d.). Retrieved April 14, 2018, from https://www.eia.gov/dnav/ng/ng_pri_sum_dcu_sNV_m.htm
[19] "Ammonia Report" *Fertecon Agribusiness Intelligence*. 01 Feb. 2018.

obtained from the 2018 ICIS Americas Chemicals Outlook report[20]. Interestingly, this report showed that the price of bulk caustic soda had increased nearly twofold relative to historic norms in the latter half of 2017. We assume this to be a simple market fluctuation, and choose to forgo that as our costing basis in favor of historic norms referenced in the same report. Costing for the potassium hydroxide was derived from observation of pricing set by bulk sellers on Alibaba. It was assumed that the monoammonium phosphate in the ammonia recycle loop would be replaced on a weekly basis and costing was derived from Alibaba.

To operate our reactor such that we meet our production requirements, 434lb of Pt-Rh catalytic gauze is required. Since bulk pricing on such a catalyst is not readily available, the costing was performed using market prices for both constituent metals, assuming a 90%-10% platinum-rhodium split[21]. We also assumed that the catalytic gauze has approximately a half-year useful lifespan and we did not factor in potential catalyst recovery, as such necessitating two installations of catalyst per operating year.

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[20] "Americas Chemicals Outlook 2018" *ICIS*.

[21] Platinum Spot Price Live & Historical Chart. (2017, November 15). Retrieved April 14, 2018, from https://www.moneymetals.com/precious-metals-charts/platinum-price

Table 20.2. Project Utility Summary

Utility	Cost per unit ($/unit)	Required Ratio (per lb CN product)	Cost per hour of operation ($/hr)	Annual Cost ($)
Cooling Water	($1.2 x 10^{-5})/lb	35.0	$7/hr	$0.06MM
Boiler-Feed Water	($2.4 x 10^{-4})/lb	5.2	$22/hr	$0.17MM
Low Pressure Steam	$0.0055/lb	0.24	$22/hr	$0.17MM
Electricity	$0.07/kWh	0.1	$129/hr	$1.0MM
Total	-	-	-	$1.4MM

We will be producing a surplus of high pressure (500psig) steam from the waste heat boiler, eliminating the need to purchase additional steam or natural gas to facilitate any heating within the plant. The total amount of steam produced is approximately 90,000 lb/hr. After fulfilling heating requirements around the plant, we are left with roughly 70,000 lb/hr of unused high pressure steam. We initially thought about using it to drive a turbine to offset electricity costs and found that we could produce approximately 1300kW of power and put a significant dent in our electricity requirements. However, we found that it would ultimately be more lucrative to sell off our unused steam as a byproduct since it would be able to at a price of $0.0085/lb for a total of $4.6MM per year as opposed to offsetting $0.7MM per year in electricity costs.

Table 20.3. General Expenses

Expense	Relationship to Sales	Total Cost per Year ($)
Selling (or transfer) expenses	2.0% of Sales	$3.2MM
Direct Research	4.8% of Sales	$5.2MM
Allocated Research	0.5% of Sales	$0.54MM
Administrative Expenses	2.0% of Sales	$2.2MM
Management Incentive Compensation	1.25% of Sales	$1.35MM
Total	-	$12.49MM

To keep the business competitive, additional variable costs derived from sales figures must be accounted for. Since these are tied to product sales and are sensitive to market fluctuations, they are the other group of costs outside of raw materials and utilities that factor into annual operating costs, which altogether total $68.8MM in annual variable operating costs.

Section 20.2: Fixed Operating Costs

Table 20.4. Labor Expenses

Expense	Determination of Cost	Annual Cost ($)
Direct Wages and Benefits	$40/operator-hour	$2.00MM
Direct Salaries and Benefits	15% Direct Wages and Benefits	$0.3MM
Operating Supplies and Services	6% Direct Wages and Benefits	$0.12MM
Technical Assistance to Manufacturing	$60,000 per year, for each Operator per Shift	$1.4MM
Control Laboratory	$65,000 per year, for each Operator per Shift	$1.6MM
Total	-	$5.4MM

It was assumed that the plant would operate on 3 shifts of 8 hours each, with each shift having eight operators to account for the mixture of fluids and solids handling processes.

Table 20.5 Maintenance Expenses

Expense	Determination of Cost	Annual Cost ($)
Wages and Benefits	4.5% of Total Depreciable Capital	$1.3MM
Salaries and Benefits	25% of Maintenance Wages and Benefits	$0.33MM
Materials and Services	100% of Maintenance Wages and Benefits	$1.31MM
Maintenance Overhead	5% of Maintenance Wages and Benefits	$0.07MM
Total	-	$3.0MM

Table 20.6. General Fixed Expenses

Expense	Determination of Cost	Annual Cost ($)
General Plant Overhead	7.1% of Maintenance and Operations Wages and Benefits	$0.28MM
Mechanical Department Services	2.4% of Maintenance and Operations Wages and Benefits	$0.09MM
Employee Relations Department	5.9% of Maintenance and Operations Wages and Benefits	$0.23MM
Business Services	7.4% of Maintenance and Operations Wages and Benefits	$0.29MM
Property Taxes/Insurance	2% of Total Depreciable Capital	$0.58MM
Air Emissions Permit	$30,000 plus $16.98/ton emitted	$0.45MM
Total	-	$1.95MM

Tables 20.4-20.6 cover all fixed operating costs, which sum to $10.4MM. The information in the 'Determination of Cost' for each of these table is taken from *Seider et. al, 2017*, with the exception of the Air Emissions Permit expense in Table 20.6, which is taken from the website of the Nevada Division of Environmental Protection[22]. This is applicable for the vapor outlet from tower V-101 which contains CO, CO_2 and residual process CH_4 and NH_3.

[22]Permit Guidance - Nevada Division of Environmental Protection. (n.d.). Retrieved April 17, 2018, from https://ndep.nv.gov/air/permitting/permit-guidance#permit-cost

Section 21: Profitability Analysis

To get our plant up and running, we are assuming that it will take the rest of the currently calendar year to complete the design work and then all of the following year to construct the plant. The plant's profitability was calculated on a basis of 15 years of production following its startup, with production capacity starting off at half of 90% full capacity in the first year, increasing linearly to 90% of full capacity through the third year of operation and staying there through operating year 15.

Table 21.1. Profitability Measures for the plant over its 15 year operating lifespan

Profitability Measures

The Internal Rate of Return (IRR) for this project is	48.42%
The Net Present Value (NPV) of this project in 2018 is	$ 72,501,300

ROI Analysis (Third Production Year)

Annual Sales	**97,200,000**
Annual Costs	**(68,148,741)**
Depreciation	**(2,474,986)**
Income Tax	**(5,581,017)**
Net Earnings	**20,995,256**
Total Capital Investment	**36,909,345**
ROI	**56.88%**

Table 21.1 generated from Downey's profitability spreadsheet displays profitability measures for the plant in its third production year, when it reaches the goal of 90% capacity production. Assuming our cyanide product is sold at the lower end of the range given in the project statement, $0.82/lb, the project will generate an internal rate of return (IRR) of 48.42% and an Return on Investment (ROI) of 56.88%.

Table 21.2 displays Cash Flow for the project through its 15th operating year. The project breaks even during its third operating year when the plant is up to full capacity, after having a negative present value through its period of construction and below-capacity production. After breaking even, the positive cash flow generated by the plant will be consistent at roughly \$23MM/year. The development of the project's Net Present Value to its final value of \$72.5MM at the end of the plant's 15th operating year is visualized in Figure 21.1.

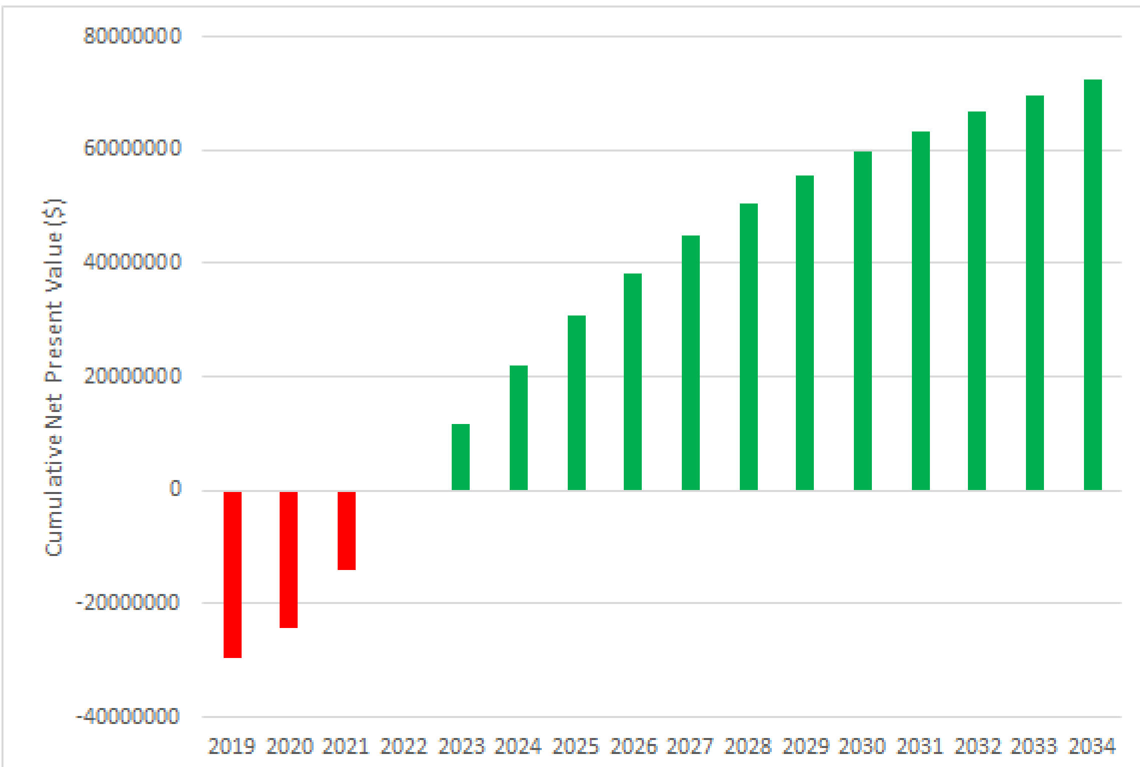

Figure 21.1. Cumulative Net Present Value of Project over 15 year plant lifespan

Table 21.2. Summary of Project Cash Flow

Cash Flow Summary

Year	Percentage of Design Capacity	Product Unit Price	Sales	Capital Costs	Working Capital	Var Costs	Fixed Costs	Depreciation	Depletion Allowance	Taxible Income	Taxes	Net Earnings	Cash Flow	Cumulative Net Present Value at 15%
2018	0%		-	-	-	-	-	-	-	-	-	-	-	-
2019	0%		-	(30,937,300)	(2,986,000)	-	-	-	-	-	-	-	(33,923,300)	(29,498,600)
2020	45%	$1.80	48,600,000	-	(1,493,000)	(28,895,800)	(10,357,200)	(5,815,300)	-	3,531,700	(741,700)	2,790,100	7,112,400	(24,120,600)
2021	68%	$1.80	72,900,000	-	(1,493,000)	(43,343,600)	(10,357,200)	(9,304,500)	-	9,894,700	(2,077,900)	7,816,800	15,628,300	(13,844,800)
2022	90%	$1.80	97,200,000	-	-	(57,791,500)	(10,357,200)	(5,582,700)	-	23,468,600	(4,928,400)	18,540,200	24,122,900	(52,400)
2023	90%	$1.80	97,200,000	-	-	(57,791,500)	(10,357,200)	(3,349,600)	-	25,701,700	(5,397,300)	20,304,300	23,653,900	11,707,700
2024	90%	$1.80	97,200,000	-	-	(57,791,500)	(10,357,200)	(3,349,600)	-	25,701,700	(5,397,300)	20,304,300	23,653,900	21,934,000
2025	90%	$1.80	97,200,000	-	-	(57,791,500)	(10,357,200)	(1,674,800)	-	27,376,500	(5,749,100)	21,627,400	23,302,200	30,694,100
2026	90%	$1.80	97,200,000	-	-	(57,791,500)	(10,357,200)	-	-	29,051,300	(6,100,800)	22,950,500	22,950,500	38,196,700
2027	90%	$1.80	97,200,000	-	-	(57,791,500)	(10,357,200)	-	-	29,051,300	(6,100,800)	22,950,500	22,950,500	44,720,700
2028	90%	$1.80	97,200,000	-	-	(57,791,500)	(10,357,200)	-	-	29,051,300	(6,100,800)	22,950,500	22,950,500	50,393,700
2029	90%	$1.80	97,200,000	-	-	(57,791,500)	(10,357,200)	-	-	29,051,300	(6,100,800)	22,950,500	22,950,500	55,326,700
2030	90%	$1.80	97,200,000	-	-	(57,791,500)	(10,357,200)	-	-	29,051,300	(6,100,800)	22,950,500	22,950,500	59,616,300
2031	90%	$1.80	97,200,000	-	-	(57,791,500)	(10,357,200)	-	-	29,051,300	(6,100,800)	22,950,500	22,950,500	63,346,400
2032	90%	$1.80	97,200,000	-	-	(57,791,500)	(10,357,200)	-	-	29,051,300	(6,100,800)	22,950,500	22,950,500	66,590,000
2033	90%	$1.80	97,200,000	-	-	(57,791,500)	(10,357,200)	-	-	29,051,300	(6,100,800)	22,950,500	22,950,500	69,410,500
2034	90%	$1.80	97,200,000	-	5,972,000	(57,791,500)	(10,357,200)	-	-	29,051,300	(6,100,800)	22,950,500	28,922,500	72,501,300

Variable costs for the process amount to \$68.8MM per year, which is almost a factor of 7 greater than the amount of \$10.4MM per year for fixed operating costs. Since variable costs make up most of the plant's yearly operating costs, it is useful to visualize each component's contribution on an annual basis, as is displayed in Figure 21.2.

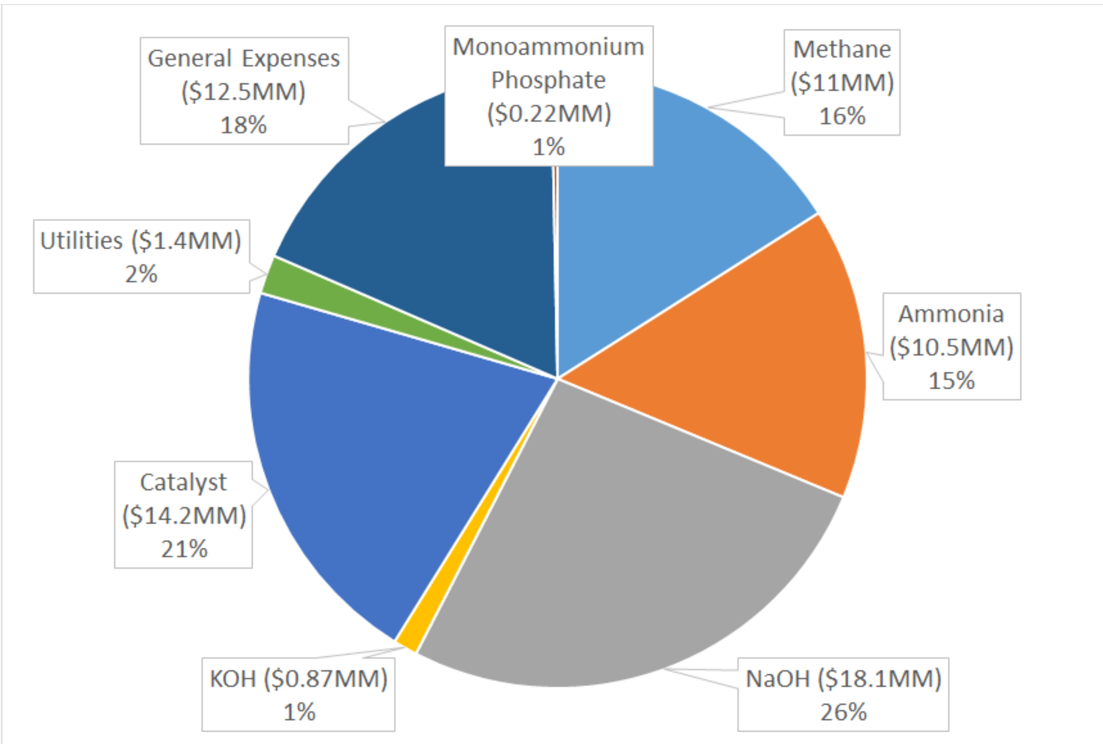

Figure 21.2. Breakdown of Annual Variable Costs

Since we observed very high fluctuations in the pricing of some of our raw materials, most notably sodium hydroxide, a sensitivity analysis was performed to gauge the project's profitability under stressful external financial factors, displayed in Table 21.3. Note that this table was generated using \$1.8/kg product rather than \$0.82/lb product. Product price was varied with respect to variable costs to generate internal rates of return under differing financial conditions. The price was varied within ±10% and the variable costs were varied within ±80%.

At the base case price of $1.8/kg, Table 21.3 shows that the project maintains a positive IRR with an increase of 40% in variable costs, but flips to a negative IRR when variable costs are increased 60%, indicating that the project could withstand a potential increase in variable costs of close to 50% and maintain a positive internal rate of return.

Table 21.3. Sensitivity analysis of product price versus variable costs

		Variable Costs								
		$12,842,561	$25,685,121	$38,527,682	$51,370,243	***$64,212,804***	$77,055,364	$89,897,925	$102,740,486	$115,583,047
Product Price	$1.62	99.70%	84.28%	68.42%	51.88%	34.11%	13.04%	Negative IRR	Negative IRR	Negative IRR
	$1.66	101.98%	86.67%	70.93%	54.56%	37.11%	17.01%	Negative IRR	Negative IRR	Negative IRR
	$1.69	104.25%	89.03%	73.41%	57.21%	40.03%	20.68%	-11.10%	Negative IRR	Negative IRR
	$1.73	106.50%	91.37%	75.86%	59.81%	42.89%	24.13%	-2.40%	Negative IRR	Negative IRR
	$1.76	108.73%	93.68%	78.28%	62.38%	45.68%	27.42%	3.70%	Negative IRR	Negative IRR
	$1.80	110.95%	95.98%	80.68%	64.92%	48.42%	30.57%	8.64%	Negative IRR	Negative IRR
	$1.84	113.15%	98.26%	83.06%	67.42%	51.12%	33.62%	12.93%	Negative IRR	Negative IRR
	$1.87	115.33%	100.52%	85.42%	69.90%	53.77%	36.57%	16.82%	Negative IRR	Negative IRR
	$1.91	117.50%	102.76%	87.75%	72.34%	56.37%	39.45%	20.42%	-9.86%	Negative IRR
	$1.94	119.65%	104.99%	90.06%	74.76%	58.94%	42.27%	23.81%	-1.94%	Negative IRR
	$1.98	121.78%	107.19%	92.35%	77.16%	61.48%	45.02%	27.04%	3.86%	Negative IRR

Tables 21.4 and 21.5 were then constructed to see if varying fixed costs and total permanent investment would have similarly substantial effects on the project's IRR. Like in Table 21.3, price was varied within ±10% and the costs in question, both fixed costs and total permanent investment, were varied within ±80%. Table 21.4 indicates that even with an 80% increase in annual fixed costs, the project still maintains a 33% internal rate of return. Table 21.5 indicates that increases in total permanent investment will be more impactful on project finances than variations in fixed costs, with an 80% increase in total permanent investment leading to a 15.5% IRR. Ultimately, these three tables indicate that the project can remain profitable in the face of fluctuations in fixed costs and total permanent investment in excess of 80%, and fluctuations in variable costs up to around 50%.

Table 21.4. Sensitivity analysis of product price versus fixed costs

		Fixed Costs								
		$2,071,444	$4,142,887	$6,214,331	$8,285,774	***$10,357,218***	$12,428,661	$14,500,105	$16,571,548	$18,642,992
Product Price	$1.62	50.58%	46.43%	42.30%	38.20%	34.11%	30.02%	25.92%	21.77%	17.55%
	$1.66	53.42%	49.30%	45.21%	41.15%	37.11%	33.08%	29.06%	25.02%	20.93%
	$1.69	56.22%	52.12%	48.06%	44.03%	40.03%	36.05%	32.09%	28.13%	24.14%
	$1.73	58.96%	54.89%	50.86%	46.86%	42.89%	38.95%	35.03%	31.12%	27.22%
	$1.76	61.66%	57.61%	53.60%	49.62%	45.68%	41.77%	37.89%	34.03%	30.19%
	$1.80	64.32%	60.29%	56.30%	52.34%	48.42%	44.54%	40.69%	36.87%	33.07%
	$1.84	66.94%	62.93%	58.95%	55.02%	51.12%	47.26%	43.43%	39.64%	35.87%
	$1.87	69.52%	65.53%	61.57%	57.65%	53.77%	49.92%	46.12%	42.35%	38.61%
	$1.91	72.07%	68.09%	64.15%	60.24%	56.37%	52.55%	48.76%	45.01%	41.30%
	$1.94	74.59%	70.62%	66.69%	62.80%	58.94%	55.13%	51.36%	47.63%	43.93%
	$1.98	77.07%	73.12%	69.20%	65.32%	61.48%	57.68%	53.92%	50.20%	46.52%

Table 21.5. Sensitivity analysis of product price versus total permanent investment

		Total Permanent Investment								
		$6,187,465	$12,374,930	$18,562,395	$24,749,859	***$30,937,324***	$37,124,789	$43,312,254	$49,499,719	$55,687,184
Product Price	$1.62	208.60%	119.06%	73.44%	48.88%	34.11%	24.32%	17.33%	12.03%	7.81%
	$1.66	223.53%	127.93%	79.07%	52.83%	37.11%	26.76%	19.41%	13.86%	9.49%
	$1.69	237.95%	136.62%	84.59%	56.69%	40.03%	29.11%	21.40%	15.62%	11.08%
	$1.73	251.87%	145.11%	90.00%	60.48%	42.89%	31.40%	23.33%	17.30%	12.60%
	$1.76	265.30%	153.44%	95.32%	64.19%	45.68%	33.63%	25.20%	18.93%	14.06%
	$1.80	278.28%	161.59%	100.56%	67.85%	48.42%	35.81%	27.01%	20.50%	15.46%
	$1.84	290.81%	169.57%	105.70%	71.44%	51.12%	37.95%	28.79%	22.03%	16.82%
	$1.87	302.92%	177.40%	110.77%	74.98%	53.77%	40.04%	30.52%	23.52%	18.14%
	$1.91	314.62%	185.07%	115.76%	78.47%	56.37%	42.10%	32.22%	24.98%	19.42%
	$1.94	325.93%	192.60%	120.67%	81.91%	58.94%	44.13%	33.89%	26.40%	20.67%
	$1.98	336.87%	199.98%	125.52%	85.30%	61.48%	46.13%	35.53%	27.80%	21.89%

Section 22: Other Considerations

Section 22.1 Environmental

Our plant's operation of the Andrussow process will result in a significant output of greenhouse gases on an annual basis, amounting to around 21M tonnes of CO and 2.6M tonnes of CO2 per year. Likewise, roughly 870 tonnes of CH4 and 640 tonnes of NH3 need to be dealt with on an annual basis, which will be accomplished through the use of a flare system. Since the plant is producing in excess of 100 tonnes of emission per year, an annually-renewed state permit is necessary for plant operation. Apart from atmospheric emissions, the plant will deal with a significant amount of aqueous ammonia and cyanide-containing waste streams as well. This aqueous waste will be collected in a concrete sump and sent to thermal decomposition tanks to be treated.

Section 22.2 Health and Safety

This project deals with several hazardous chemicals, the most dangerous of which is hydrogen cyanide. In order to produce HCN, methane and ammonia, which both can be explosive, are combusted in our reactor. To avoid potential detonations, the mixture of CH_4 and NH_3 must be fed in a proportion with air that lies outside the lower and upper explosivity limits for such a mixture, represented by lines A and B in Figure 22.1 below[23].

[23] US6743407B2, Roehm GmbH & Co. KG, July 2001

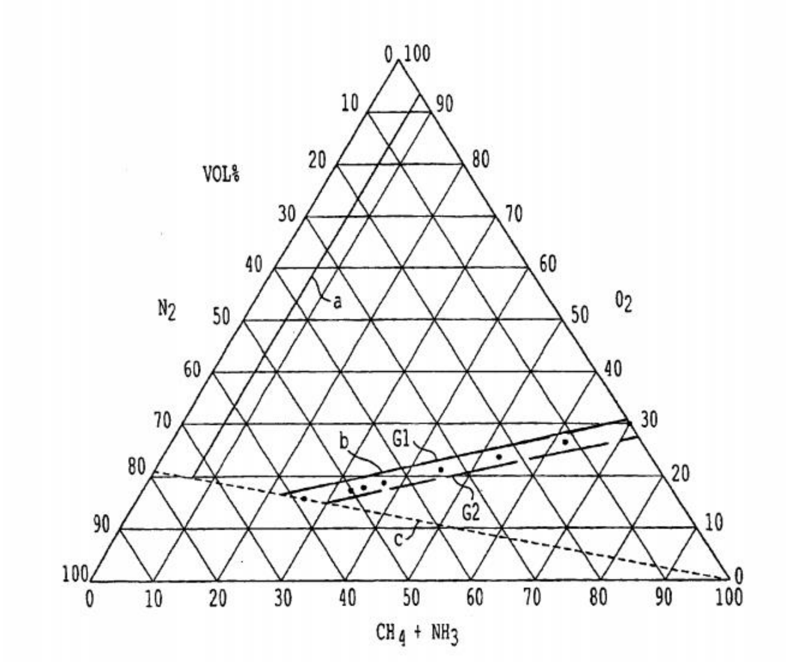

Figure 22.1. Ternary phase diagram detailing explosivity limits of mixtures of nitrogen, oxygen, and methane and ammonia (Line ‘a’: lower explosivity limit for mixture; Line ‘b’: upper explosivity limit for mixture; Lines ‘G1’ and ‘G2’: boundaries on ideal feed mixture composition for Andrussow process; Line ‘c’: denotes mixtures of air, methane and ammonia).

The presence of hydrogen cyanide up through the caustic absorber necessitates the implementation of very careful safety procedures in order to ensure no workers come into harm’s way. HCN is dangerous to human life at 5ppm, so there will need to be an extensive and sensitive monitoring system throughout the plant to detect any leaks, coupled with safety interlocks to facilitate any necessary equipment shutdowns. These instruments and interlocks will need to be frequently checked and calibrated. The reactor system will be designed with adequate pressure relief in mind to prevent any runaway deflagrations that may arise in the vessel. In the process segment handling HCN, piping will need to be fabricated without flanges and all surrounding equipment will need to be rated as explosion-proof.

Section 22.3: Process Control

The process will require very sensitive control mechanisms for the composition of the reactor inlet to ensure that there is not a detonation within the vessel. This controller will need to manipulate the flows of Streams 1, 3, 5, and 20 to ensure that the feed stream to the reactor lies outside of the explosivity range of a mixture of methane and ammonia in nitrogen and oxygen. Likewise, temperature control mechanisms will need to be in place for the absorption columns, stripper, and crystallizer since the process's separation operations are sensitive to temperature.

Section 22.4: Plant Location

The plant will be located on land owned by a gold-mining operation in Nevada. The location has access to natural gas and rail transportation, but requires the installation of onsite wastewater treatment. The plant will need to comply with state and federal level construction and operations regulations, but its remote location makes it such that residential neighbors will not need to be factored in to considerations of plant layout and operation. Likewise, the plant's location in the Nevada desert eliminates concerns regarding the disruption of sensitive biomes.

Section 22.5: Transport

Sodium cyanide briquettes will be stored on-site in a 1000 to 2000 tonne capacity warehouse. The briquettes will be packaged using a "bag/box" method. The outer layer of the bag is comprised of a woven polypropylene material while the inner layer is a waterproof polyethylene liner.[24] These bags are placed in one tonne boxes that are lined and sealed to

[24] http://www.epa.wa.gov.au/sites/default/files/API_documents/EPA-bulletin_0425.pdf

prevent entrance of moisture and protection from outside environment. The bag/box packaging arrangement would be transported in standard freight containers.

Section 23: Conclusion

When at full capacity, the proposed plant will produce 61,500 metric tons of sodium cyanide and 2,100 metric tons of potassium cyanide on an annual basis. Profitability analyses indicate a Net Present Value of $72.5MM after 15 operating years with an Internal Rate of Return of 48.42%.

There are potential opportunities to refine certain segments of the project to further maximize economic viability. Reactors utilizing the Andrussow process are operated under varying temperatures, pressures, inlet feed compositions, and catalyst geometries. Sufficient funds could be sunk into research to determine if our chosen reactor operating conditions are indeed optimal or if we could further increase our production yield of hydrogen cyanide. This would be accomplished through a combination of laboratory and pilot plant work.

Further market research should also be performed in order to confirm assumptions about raw material costs, which comprise a majority of yearly operating expenses. From the sensitivity analysis, the project can withstand relatively high fluctuations in variable costs, so this would become significant only in the case of a huge shift in the market for a particular material.

This project ultimately has a high Return On Investment and we recommend investing, but we also caution being aware of the market conditions for the necessary raw materials.

Section 24: Acknowledgements

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Section 26: Appendix A

Sodium and Specialty Cyanides Production Facility
(recommended by Stephen M. Tieri, DuPont)

Sodium cyanide and specialty cyanides are commercially valuable materials used in wide variety of applications and industries; including electroplating, mining and metal processing, and organic chemicals production. Sodium cyanide is used throughout the world and is instrumental in the extraction of gold, silver, and other precious metals naturally occurring in low concentrations in ore. As a chemical intermediate, it provides a supply of hydrogen cyanide in regions where a local supply is not available, since sodium cyanide can be transported and stored.

Driven by the current and forecasted growth in precious metals, consumer electronics, and electronics materials, the global sodium cyanide demand is expected to grow by 4 percent annually, with a forecasted global demand of 1.1 million tones in 2018. While there have been initiatives to substitute sodium cyanide in gold recovery because of potential environmental danger if not handled responsibly, it remains the most environment-friendly of the possible substitutes.

For this project, your company's business team identified and is negotiating an agreement for a manufacturing site in Rochester, Nevada. This partner site location is a currently undeveloped section of an existing manufacturing site, with access to natural gas and electricity, but with limited aqueous waste treatment. The site host company is a medium sized gold/silver ore mining and recovery company, interested in an on-site partner for future capacity expansion.

Sodium cyanide is typically produced by the neutralization of hydrocyanic acid with aqueous sodium hydroxide, following the chemistry shown below (1). Water is evaporated from the aqueous solution to generate solid product.

$$HCN + NaOH \longrightarrow NaCN + H_2O \qquad (1)$$

Dry NaCN solids are then compacted into briquettes prior to loading into their final shipping container. Specialty cyanides (KCN, LiCN, etc.) are produced using similar chemistry, but using their respective cation caustic solutions in place of NaOH.

There are several options for commercial production of hydrogen cyanide (HCN). However, for this location and capacity requirement, HCN is expected to be generated on-site, produced directly by either the Andrussow or Degussa process. While both react ammonia and methane over a precious metal catalyst, oxygen is present in the Andrussow process reaction (2) and excluded in the Degussa process reaction (3). Additionally, there are different impurity profiles generated by the two processes.

$$CH_4 + NH_3 + 1.5\ O_2 \longrightarrow HCN + 3\ H_2O \tag{2}$$

$$\mathbf{CH_4 + NH_3 \rightarrow HCN + 3\ H_2} \tag{3}$$

Your project team has been assembled to design this new cyanides production facility using the best commercially demonstrated, sustainable, and economically viable technology. The business objective is to deliver a commercial scale facility with the capacity to produce 60 k Tonnes/yr (60,000 MT/yr, 60 MM kg/yr) of sodium cyanide (NaCN) and 2 k Tonnes/yr (2,000 MT/yr, 2 MM kg/yr) of total specialty cyanides (KCN, LiCN, CaCN). Your team is also responsible for identifying and minimizing the required investment and operating costs, and identifying any critical economic sensitivities to raw materials, product, utility, or equipment pricing, use quantity, and quality.

The product quality and purity should meet or exceed current industry expectations, 98% ±1% product as solid briquettes or as a 10 - 25 wt% solution of NaCN in water. All solution product must be used/consumed

onsite, with a maximum of 15% total solution sales (dry cyanide basis). Sodium cyanide product price is expected to be in the range of $1.80 - $2.00, and fluctuate with demand and gold pricing. Natural gas is available onsite at market price and at average US composition. The team is expected to identify whether additional purification of the natural gas feed is necessary prior to use, depending on the resulting product quality, investment, and cost impacts. Ammonia, NaOH, and other alkali metal hydroxides are available at market prices. The facility should have the capability to ship briquettes in rail cars, ISO containers, hopper trailers, and 1 ton bags/supersacks. Any unconverted ammonia is expected to be thermally treated, recovered, or converted to a co-product to minimize air emissions.

While sodium and specialty cyanides provide meaningful benefits to society, they have the potential for harm if not managed properly. Cyanide is acutely toxic to humans. Liquid or gaseous hydrogen cyanide and alkali salts of cyanide can enter the body through inhalation, ingestion or absorption through the eyes and skin. The toxicity of these materials represent a potential environmental or health hazard if the product is not used, transported, and handled correctly. The process, systems, and equipment will need to minimize the potential for material contact with personnel and the environment, including safety systems with extensive alarm and monitoring systems designed to detect, mitigate, and contain an HCN release.

The plant design should be as environmentally friendly as possible, and as necessary as required by state and federal emissions legislation. It is expected that the facility will include emission control equipment as a part of the process design and operation. Recover and recycle process materials to the maximum economic extent. Also, energy consumption should be minimized, to the extent economically justified. The plant design must also be controllable and safe to operate. As the process technology integration and design team, you will be there for the start-up and will have to live with whatever design decisions you have made.

Undoubtedly, you will need additional data beyond that given here and listed in the references below. Cite any literature data used. If required, make reasonable assumptions, state them, and identify whether your design or economics are sensitive to the assumptions you have made.

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Section 26: Appendix B

Appendix B.1: Heat Exchangers

Heat exchanger sizing was based on the surface area required for heat transfer, which was calculated from Equation 1 below. From ASPEN, heat duties for each exchanger was obtained in addition to inlet and outlet temperatures. Table 12.5 in Seider et. al. was referenced to select an appropriate estimate for overall heat transfer coefficient, which depended on process fluid and heat transfer medium. Temperature changes for cooling water streams were taken to be from 90F to 120F, as recommended by Seider et. al. Heat transfer using high pressure steam and boiler feed water was assumed to come from the respective latent heats of condensation/vaporization. High pressure steam condensation was assumed to occur at constant temperature of 470F, which is the saturation pressure of 500 psig steam. The required amount of utility flow required was based on heat exchanger duty and heat of vaporization/condensation [boiler feed water & high pressure steam] of utility stream or the heat capacity (Cp) and allowed temperature change [cooling water].

$$Q = UA\Delta T_{lm} = U * A * \frac{(T_{hi}-T_{co})-(T_{ho}-T_{ci})}{\ln(\frac{T_{hi}-T_{co}}{T_{ho}-T_{ci}})} \qquad \text{Equation 1}$$

where:
Q = duty of exchanger [BTU/hr]
U = heat transfer coefficient [BTU/(hr*ft*F)]
A = surface area of exchanger [ft^2]
T_{hi} = inlet temperature of hot stream [F]
T_{ho} = outlet temperature of hot stream [F]
T_{ci} = inlet temperature of cold stream [F]
T_{co} = outlet temperature of cold stream [F]

Sample Calculation for E-102 (After the process HX pre absorber)

Input Parameters

Q	678,613	BTU/hr
T_{hi}	324	F
T_{ho}	158	F
T_{ci}	90	F
T_{co}	120	F
U	50	BTU/(hr*ft^2*F)

$$\Delta T_{lm} = 124\ F$$

$$A = \frac{Q}{U * \Delta T_{lm}} = \frac{678613\ BTU/hr}{50 \frac{BTU}{hr * ft2 * F} * 124\ F} = 110\ ft^2$$

$$Cooling\ Water\ Flow = \frac{Q}{cp * \Delta T} = \frac{678613 \frac{BTU}{hr}}{1 \frac{BTU}{lb * F} * 30\ F} = 22{,}620 \frac{lbs}{hr}$$

Appendix B.2: Absorber/Stripping Column

Tower diameter of the absorption/stripping columns (V-100,V-101,V-102) was determined by calculating entrainment flooding velocities using equations presented in Chapter 13 of Seider et. al, which depended on vapor and liquid flow rates and their properties up and down the tower.

$$U_f = C_{sb} * F_{ST} * F_F * F_{HA} \sqrt{\frac{\rho_L - \rho_V}{\rho_v}}$$

$$F_{LG} = \frac{L}{V} \sqrt{\frac{\rho_V}{\rho_L}}$$

$$C_{sb} = f(F_{LG}, tray\ spacing) \ldots .Figure\ 19.4\ Seider\ et\ al$$

$$D_T = \left(\frac{4 * V}{(f * U_f)\pi * \left(1 - \frac{A_d}{A_t}\right) * \rho_V}\right)^{1/2}$$

where:
U_f = flooding velocity [ft/hr]
C_{sb} = parameter from Figure 13.4 in Seider et. al [ft/s]
F_{ST} = surface tension factor = $(\sigma/20^{0.20}$
σ = surface tension of liquid phase [dyne/cm]
F_F = foaming factor
F_{HA} = hole area factor
ρ_L = density of liquid phase [lb/ft^3]
ρ_v = density of vapor phase [lb/ft^3]
L = liquid mass flow rate [lb/hr]
V = vapor mass flow rate [lbs/hr]
A_D = down comer area [ft^2]
A_T = total tray area [ft^2]
D = diameter [ft]
f = fraction of flooding velocity

Sample Calculation for V-100

Input Parameters

f	0.80	80% flooding
ρ_L	62.4	lb/ft^3
ρ_v	0.047	lb/ft3

L	33,677	lb/hr
V	123,807	lb/hr
F_F	1	(non-foaming)
F_{HA}	1	-
F_{ST}	1.39	-
C_{SB}	0.3	18 in plate spacing
$(1-A_d/A_t)$	0.9	$F_{LG} < 0.1$

$$U_f = 177{,}147\frac{ft}{hr}$$

$$D_T = \left(\frac{4 * 123807\ \frac{lb}{hr}}{\left(0.8 * 177147\frac{ft}{hr}\right)\pi * (0.9) * 0.047\frac{lb}{ft^3}}\right)^{\frac{1}{2}} = 5.1\ ft$$

Tower height and number of trays were determined using the Kremser Shortcut Method described in Chapter 13 of Seider et. al which are valid for adiabatic absorbers with one feed and one absorbent. K –values was referenced from _______ for a HCN/Water system.

$$A = \frac{L}{K * V}$$

$$\varphi = \frac{A - 1}{A^{N+1} - 1}$$

$$N_{act} = \frac{N}{E}$$

Where:
A = absorption factor
L = Liquid molar flow rate [kmol/hr]
V = Vapor molar flow rate [kmol/hr]
K = Vapor-liquid equilibrium ratio
(1-Φ) = Fraction of key component to be absorbed
N = Number of theoretical plates
E = Plate efficiency
N_{act} = Number of Actual Plates

Sample Calculation for V-100

Input Parameters

L	697	Kmol/hr
V	2465	Kmol/hr
K	0.132	(Adjusted for T = 158 F)
1-Φ	0.9999	--
E	0.30	Conservative estimate for absorber columns, pg. 391 Seider et al

$$A = \frac{697\ kmol/hr}{0.132 * 2465\ kmol/hr} = 2.12$$

$$\Phi\ = 0.0001 = \frac{2.12 - 1}{2.12^{N+1} - 1}$$

$$N = 14.5$$

$$N_{act} = \frac{14.5}{0.3} = 48.3 = 49$$

$$Tower\ Height = N_{act} * Plate\ Height = 49 * 1.5\ ft = 73.5\ ft$$

Additional 14 ft of tower height was included to height calculated above in order to account for vapor-liquid disengagement and surge sump.

$$Total\ Tower\ Height = 73.5\ ft + 14\ ft = 87.5\ ft$$

Appendix B.3: Storage Tanks

Both storage tanks (TK-100, TK-101) were sized based on the amount of feed that is desired to be maintained and required flow rate based on production requirements. For each tank, a volumetric capacity factor of 1.17 was used such that each tank operates at a maximum capacity of 85%.

$$V = \frac{(\dot{m} * t * 1.17)}{\rho}$$

where:
V = Volume of Tank [ft^3]
ṁ = Mass flow rate out of tank [lbs/day]
ρ = density of fluid [lbs/ft^3]
t = time capacity factor [days]

Sample Calculation for TK-101

Input Parameters

ṁ	706,368	Lbs/day
ρ	94.9	Lbs/ft^3 (50% wt NaOH)
t	7	days

$$V = \frac{706368 \frac{lbs}{day} * 7\ days * 1.17}{94.9\ lbs/ft3} = 59{,}053\ ft^3$$

>> Assuming a height to diameter ratio of 1

$$Diameter = \left(\frac{4 * V}{\pi}\right)^{\frac{1}{3}} = \left(\frac{4 * 59053}{3.1415}\right)^{\frac{1}{3}} \cong 42\ ft = Height$$

Appendix B.4: Hot Surface Precipitator (E-103)

Sizing for the hot surface precipitator was based on the surface area required to precipitate out 80% of the aqueous sodium carbonate and sodium bicarbonate being fed to the unit, which was calculated from the equations below. Mass flow rates for these components were determined using ASPEN Plus. Using densities of solid sodium carbonate and sodium bicarbonate, volumes were thus determined for these components precipitated out on the inside surface of the tubes. It was recommended by industrial consultants that a 1 mm thick layer of precipitate buildup on the surface of the tubes would lead to inefficient heat transfer. Using this assumption, as well as assuming the units would have to be switched out and the precipitate removed every 2 shifts (16 hours), an area for the inner surface of the tubes was determined.

The aqueous stream containing sodium carbonate and bicarbonate enters the unit at a temperature within the range of sodium carbonate/bicarbonate precipitation. Therefore, a small temperature increase of 9F (5C) was assumed to be sufficient for providing a boundary layer at the inner surface of the tubes that was hotter than the bulk. The required heat transfer for this temperature increase was determined using ASPEN Plus, and the steam utility requirement was found using the latent heat of condensation of high pressure steam at 470F, 500 psig. For an example utility requirement calculation, see Appendix A.1.

$$A = \frac{m*t}{\rho*\tau}$$

where:
A = area [ft^2]
m = mass flow rate [lb/hr]
t = precipitation time [hr]
ρ = density [lb/ft^3]
τ = buildup thickness [ft]

Input Parameters:

m	424	Lbs/hr
ρ	158.6	Lbs/ft^3
t	16	hours
$\boldsymbol{\tau}$	0.00328	ft

$$A = \frac{424 \frac{lb}{hr} * 16}{158.6 \frac{lb}{ft^3} * 0.00328\, ft} = 13004\, ft^2$$

Appendix B.5: Andrussow Reactor Design (R-100)

The Andrussow reactor was designed based on linear gas velocity and catalyst contact time typically used in industrial operations. US Patent 2011/171101 recommends that the feed gas to the reactor enters with a linear velocity of up to 5 meters per second (16.4 feet per second). A cross-sectional area for the cylindrical reactor and thus a diameter were determined using the linear velocity and the volumetric flow rate of the gas feed, as shown in the proceeding calculations. Once the diameter was determined, a height was determined using a H/D ratio of 1.7, also recommended in US Patent 2011/171101, which is tall enough to encase the waste-heat boiler and allow 3 ft of space between it and the gauze packing.

$$A = \frac{V}{v}$$

$$D = \left(\frac{4 * A}{\pi}\right)^{\frac{1}{3}}$$

$$H = 1.4 * D$$

where:

A = cross-sectional area [ft^2]
V = volumetric flow rate [ft^3/s]
v = linear gas velocity [ft/s]
D = reactor diameter [ft]
H = reactor height [ft]

Input Parameters:

V	1403	cuft/s
v	16.4	ft/s

$$A = \frac{1403\ cuft/s}{16.4\ ft/s} = 85.5\ ft^2$$

$$D = \left(\frac{4 * 85.5\ ft^2}{\pi}\right)^{\frac{1}{3}} = 10.4\ ft$$

$$H = 1.4 * 10.4\ ft = 14.6\ ft$$

In order to determine catalyst requirements, the linear gas velocity was used in combination with a catalyst contact time of 0.0006 seconds. An overall catalyst thickness of 3 mm was determined, which corresponds to approximately 40 layers of standard 0.076 mm thick Rh-Pt gauze.

$$\tau = t * v$$

$$n = \frac{\tau}{\tau_o}$$

where:

τ = catalyst thickness [m]
v = linear gas velocity [m/s]
n = number of gauze layers
τ_o = typical gauze thickness [m]

Input Parameters:

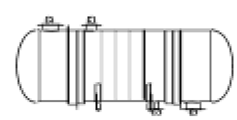
t	0.0006	s
$\boldsymbol{\tau_o}$	0.076	mm

$$\tau = 0.0006\ s * 5000\frac{mm}{s} = 3\ mm$$

$$n = \frac{3\ mm}{0.076\ mm} = 39.5 \cong 40$$

Appendix B.6: Waste-Heat Boiler TEMA Design

Heat Exchanger Specification Sheet

1	Company:							
2	Location:							
3	Service of Unit:		Our Reference:					
4	Item No.:		Your Reference:					
5	Date:	Rev No.:	Job No.:					
6	Size : 124.803 - 156	in	Type:	BEM	Horizontal	Connected in: 1	parallel	1 series
7	Surf/unit(eff.)	33454.7	ft^2	Shells/unit	1	Surf/shell(eff.)	33454.7	ft^2
8	**PERFORMANCE OF ONE UNIT**							
9	Fluid allocation		Shell Side		Tube Side			
10	Fluid name				RXNPROD			
11	Fluid quantity, Total	lb/h	89852		124067			
12	Vapor (In/Out)	lb/h	0	89852	124067	124067		
13	Liquid	lb/h	89852	0	0	0		
14	Noncondensable	lb/h	0	0	0	0		
15								
16	Temperature (In/Out)	°F	469.8	470.17	2058.8	600.26		
17	Bubble / Dew point	°F	470.17 / 470.17	470.12 / 470.13	/	/		
18	Density Vapor/Liquid	lb/ft^3	/ 46.438	0.929 /	0.025 /	0.057 /		
19	Viscosity	cp	/ 0.111	0.0181 /	0.0546 /	0.029 /		
20	Molecular wt, Vap			18.02	22.83	22.83		
21	Molecular wt, NC							
22	Specific heat	BTU/(lb-F)	/ 1.6515	0.4694 /	0.3969 /	0.3407 /		
23	Thermal conductivity	BTU/(ft-h-F)	/ 0.362	0.022 /	0.08 /	0.035 /		
24	Latent heat	BTU/lb	751	751				
25	Pressure (abs)	psi	514.7	514.48	29.39	28.59		
26	Velocity (Mean/Max)	ft/s	2.16 / 5.97		55.83 / 92.48			
27	Pressure drop, allow./calc.	psi	1	0.22	14.7	0.8		
28	Fouling resistance (min)	ft^2-h-F/BTU	0		0	0	Ao based	
29	Heat exchanged	67528740	BTU/h		MTD (corrected)	602.54	°F	
30	Transfer rate, Service	3.35	Dirty	7.08	Clean	7.08	BTU/(h-ft^2-F)	
31	**CONSTRUCTION OF ONE SHELL**						**Sketch**	
32				Shell Side	Tube Side			
33	Design/Vacuum/test pressure		psi	580.15 / /	43.51 / /			
34	Design temperature		°F	536	2129			
35	Number passes per shell			1	1			
36	Corrosion allowance		in	0	0			
37	Connections	In	in	1 6 / -	1 26 / -			
38	Size/Rating	Out		1 16 / -	1 26 / -			
39	Nominal	Intermediate		/ -	/ -			
40	Tube #: 15606	OD: 0.75	Tks. Average 0.165	in	Length: 13	ft	Pitch: 0.9375 in	Tube pattern: 30
41	Tube type: Plain		Insert: None		Fin#:	#/in	Material: SS 316	
42	Shell SS 316	ID 10.4003	OD 10.8137	ft	Shell cover	-		
43	Channel or bonnet	SS 316			Channel cover	-		
44	Tubesheet-stationary	SS 316	-		Tubesheet-floating	-		
45	Floating head cover	-			Impingement protection	None		
46	Baffle-cross SS 316	Type	Single segmental	Cut(%d)	20.08	V Spacing: c/c	24.96	in
47	Baffle-long -		Seal Type			Inlet	28.0669	in
48	Supports-tube	U-bend	0		Type			
49	Bypass seal			Tube-tubesheet joint	Expanded only (2 grooves)(App.A 'i')			
50	Expansion joint	-		Type	None			
51	RhoV2-Inlet nozzle	333	Bundle entrance	5	Bundle exit	209	lb/(ft-s^2)	
52	Gaskets - Shell side	-		Tube side	Flat Metal Jacket Fibe			
53	Floating head	-						
54	Code requirements	ASME Code Sec VIII Div 1		TEMA class	R - refinery service			
55	Weight/Shell	391311.9	Filled with water	470092.1	Bundle	278897.3	lb	
56	Remarks							
57								
58								

Section 26: Appendix C

Safety Data Sheet

1. IDENTIFICATION OF THE MATERIAL AND SUPPLIER

Product Name: **AMMONIA - ANHYDROUS**

Other name(s): Ammonia anhydrous; Ammonia gas; Anhydrous ammonia; Ammonia liquid; Big N; Ammonia cylinder (used).

Recommended Use of the Chemical and Restrictions on Use Fertilizer; preparation of fertilizers; chemical synthesis; condensation catalyst; latex preservative; manufacture of explosives; rocket fuel.

Supplier: Ixom Operations Pty Ltd
ABN: 51 600 546 512
Street Address: Level 8, 1 Nicholson Street
East Melbourne Victoria 3002
Australia

Telephone Number: +61 3 9906 3000
Emergency Telephone: **1 800 033 111 (ALL HOURS)**

Please ensure you refer to the limitations of this Safety Data Sheet as set out in the "Other Information" section at the end of this Data Sheet.

2. HAZARDS IDENTIFICATION

Classified as Dangerous Goods by the criteria of the Australian Dangerous Goods Code (ADG Code) for Transport by Road and Rail; DANGEROUS GOODS.

This material is hazardous according to Safe Work Australia; HAZARDOUS CHEMICAL.

Classification of the chemical:
Flammable Gases - Category 2
Gases under pressure - Liquefied Gas
Acute Inhalation Toxicity - Category 3
Skin Corrosion - Sub-category 1B
Eye Damage - Category 1
Specific target organ toxicity (single exposure) - Category 3

The following health/environmental hazard categories fall outside the scope of the Workplace Health and Safety Regulations:
Acute Aquatic Toxicity - Category 1

SIGNAL WORD: DANGER

Hazard Statement(s):
H221 Flammable gas.
H280 Contains gas under pressure; may explode if heated.
H314 Causes severe skin burns and eye damage.
H331 Toxic if inhaled.
H335 May cause respiratory irritation.

Precautionary Statement(s):

Prevention:
P210 Keep away from heat, sparks, open flames, hot surfaces. No smoking.
P260 Do not breathe dust / fume / gas / mist / vapours / spray.
P264 Wash hands thoroughly after handling.
P271 Use only outdoors or in a well-ventilated area.
P273 Avoid release to the environment.
P280 Wear protective gloves / protective clothing / eye protection / face protection.

Response:
P301+P330+P331 IF SWALLOWED: Rinse mouth. Do NOT induce vomiting.
P303+P361+P353 IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower.
P321 Specific treatment (see First Aid Measures on Safety Data Sheet).
P363 Wash contaminated clothing before re-use.
P304+P340 IF INHALED: Remove person to fresh air and keep comfortable for breathing.
P311 Call a POISON CENTER or doctor/physician.
P305+P351+P338 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P310 Immediately call a POISON CENTER or doctor/physician.
P377 Leaking gas fire: Do not extinguish, unless leak can be stopped safely.
P381 Eliminate all ignition sources if safe to do so.
P391 Collect spillage.

Storage:
P403+P233 Store in a well-ventilated place. Keep container tightly closed.
P405 Store locked up.
P410 Protect from sunlight.

Disposal:
P501 Dispose of contents and container in accordance with local, regional, national, international regulations.

Poisons Schedule (SUSMP): S6 Poison.

3. COMPOSITION AND INFORMATION ON INGREDIENTS

Components	CAS Number	Proportion	Hazard Codes
Ammonia	7664-41-7	>99.5%	H221 H331 H314 H335 H400

4. FIRST AID MEASURES

For advice, contact a Poisons Information Centre (e.g. phone Australia 131 126; New Zealand 0800 764 766) or a doctor. Urgent hospital treatment is likely to be needed.

Inhalation:
Remove victim from area of exposure - avoid becoming a casualty. Remove contaminated clothing and loosen remaining clothing. Allow patient to assume most comfortable position and keep warm. Keep at rest until fully recovered. If patient finds breathing difficult and develops a bluish discolouration of the skin (which suggests a lack of oxygen in the blood - cyanosis), ensure airways are clear of any obstruction and have a qualified person give oxygen through a face mask. Apply artificial respiration if patient is not breathing. Seek immediate medical advice.

Skin Contact:
If spilt on large areas of skin or hair, immediately drench with running water and remove clothing. Continue to wash skin and hair with plenty of water (and soap if material is insoluble) until advised to stop by the Poisons Information Centre or a doctor. For freeze burns, immediately flood burnt area with large amounts of luke-warm water and cover with a clean, dry dressing. Do not use hot water. Seek immediate medical assistance.

Eye Contact:
Immediately wash in and around the eye area with large amounts of water for at least 15 minutes. Eyelids to be held apart. Remove clothing if contaminated and wash skin. Urgently seek medical assistance. Transport promptly to hospital or medical centre.

Ingestion:
Immediately rinse mouth with water. If swallowed, do NOT induce vomiting. Give a glass of water. Get to a doctor or hospital quickly.

Indication of immediate medical attention and special treatment needed:
Treat symptomatically. Delayed pulmonary oedema may result. Following severe exposure, the patient should be kept under medical supervision for at least 48 hours. Can cause corneal burns.

5. FIRE FIGHTING MEASURES

Suitable Extinguishing Media:
Fine water spray, normal foam, dry agent (carbon dioxide, dry chemical powder). Water spray can be used to bring down the vapour but should not be sprayed on pools of liquid ammonia. If water is used, a minimum of 100 volumes of water must be available for each volume of ammonia.

Hazchem or Emergency Action Code: 2RE

Specific hazards arising from the chemical:
Flammable gas. May form flammable vapour mixtures with air. Avoid all ignition sources. All potential sources of ignition (open flames, pilot lights, furnaces, spark producing switches and electrical equipment etc) must be eliminated both in and near the work area. Do NOT smoke. Flammable concentrations of ammonia gas can accumulate in the vapour space of storage containers/vessels. Caution should be exercised when opening.

Special protective equipment and precautions for fire-fighters:
Ammonia: The main products of combustion in air, at or above 780 °C, are nitrogen and water with small amounts of nitrogen dioxide and ammonium nitrate. Ammonia decomposes into flammable hydrogen gas at approximately 450 °C. May form flammable mixtures in air. The presence of oil or other combustible material will increase the fire hazard. Fatalaties have occurred as a result of the explosive nature of the ammonia gas. If involved in a fire, keep containers cool with water spray. If safe to do so, remove containers from path of fire. Fire-fighters to wear full body protective clothing and self-contained breathing apparatus. Consider evacuation.

6. ACCIDENTAL RELEASE MEASURES

Emergency procedures/Environmental precautions:
Shut off all possible sources of ignition. Clear area of all unprotected personnel. Do not allow container or product to get into drains, sewers, streams or ponds. If contamination of sewers or waterways has occurred advise emergency services or State Department of Agriculture.

Personal precautions/Protective equipment/Methods and materials for containment and cleaning up:
Avoid breathing in vapours. Work up wind or increase ventilation. Wear protective equipment to prevent skin and eye contamination and the inhalation of vapours. Stop leak if safe to do so.

Additional information:
GAS: For a small gas leak, increase ventilation and allow gas to vent to a safe area. For larger gas leaks, use fire hoses equipped with fog nozzles to disperse gas down-wind. Do NOT spray water directly on the leak or ammonia container.
LIQUID: Large volumes of gas will evaporate from a liquid spill. For small liquid spills, increase ventilation and allow the liquid to volatilise to safe area. For large spills, cover liquid with protein foam 150 mm thick. DO NOT HOSE LIQUID AMMONIA TO DRAIN; contact with water will accelerate vaporisation due to liberation of heat upon mixing with water.

7. HANDLING AND STORAGE

This material is a Scheduled Poison S6 and must be stored, maintained and used in accordance with the relevant regulations.

Precautions for safe handling:
Avoid skin and eye contact and breathing in vapour. Keep out of reach of children.

Conditions for safe storage, including any incompatibilities:
Store ammonia in a cool, well ventilated area, away from sources of heat or ignition and foodstuffs. Store away from oxidising agents, boron halides, acids, acid anhydrides, acid chlorides, halogens (eg. chlorine), interhalogens, heavy metals and their salts, ethylene oxide, hypochlorous acid, acetaldehyde (etc., refer to section 10). Check cylinders regularly for leaks.

The transport of liquefied ammonia in a tank or bulk container made of quenched and tempered steel is prohibited unless the liquefied ammonia contains not less than 0.2% water mass. May be an explosion hazard, especially in confined spaces.
Ensure pressure gauges and fittings are not made of copper, zinc or alloys (eg. brass).

Refer to AS/NZS 2022 Anhydrous ammonia - Storage and handling.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Ammonia: 8hr TWA = 17 mg/m^3 (25 ppm), 15 min STEL = 24 mg/m^3 (35 ppm)

As published by Safe Work Australia Workplace Exposure Standards for Airborne Contaminants.

TWA - The time-weighted average airborne concentration of a particular substance when calculated over an eight-hour working day, for a five-day working week.

STEL (Short Term Exposure Limit) - the airborne concentration of a particular substance calculated as a time-weighted average over 15 minutes, which should not be exceeded at any time during a normal eight hour work day. According to current knowledge this concentration should neither impair the health of, nor cause undue discomfort to, nearly all workers.

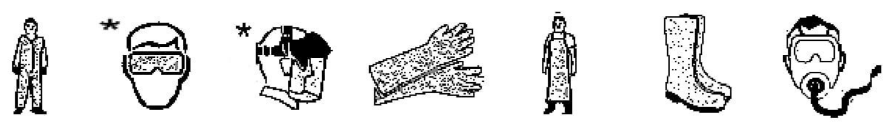
These Workplace Exposure Standards are guides to be used in the control of occupational health hazards. All atmospheric contamination should be kept to as low a level as is workable. These workplace exposure standards should not be used as fine dividing lines between safe and dangerous concentrations of chemicals. They are not a measure of relative toxicity.

Appropriate engineering controls:
Ensure ventilation is adequate to maintain air concentrations below Workplace Exposure Standards. Ammonia gas is generally lighter than air and will disperse under normal conditions. However, when ammonia liquid contacts air, the gas produced may be heavier than air. Prevent concentration in hollows or sumps. Do NOT enter confined spaces where vapour may have collected. An asphyxiant gas which can lead to the reduction of the oxygen concentration by displacement or dilution. The minimum oxygen content in air should be 18% by volume under normal atmospheric pressure.

If in the handling and application of this material, safe exposure levels could be exceeded, the use of engineering controls such as local exhaust ventilation must be considered and the results documented. If achieving safe exposure levels does not require engineering controls, then a detailed and documented risk assessment using the relevant Personal Protective Equipment (PPE) (refer to PPE section below) as a basis must be carried out to determine the minimum PPE requirements.

Individual protection measures, such as Personal Protective Equipment (PPE):
The selection of PPE is dependent on a detailed risk assessment. The risk assessment should consider the work situation, the physical form of the chemical, the handling methods, and environmental factors.

OVERALLS, CHEMICAL GOGGLES, RUBBER BOOTS, AIR MASK , GLOVES (Long), APRON.
* Not required if wearing air supplied mask.



GENERAL: Avoid all contact. Ensure safety shower and eyewash station is close at hand. Persons who could be subject to ammonia exposure must not wear contact lenses. Always wash hands before smoking, eating, drinking or using the toilet. Wash contaminated clothing and other protective equipment before storage or re-use.

EYE PROTECTION: Wear gas tight goggles which have a seal between the face and the frame. A full face shield shall only be worn to supplement the protection provided by the gas tight goggles.

SKIN PROTECTION: Wear coveralls, or full length trousers with a long sleeved shirt, with gloves and boots. Available information suggests that gloves made from chlorobutyl-proofed fabric or butyl rubber should be suitable for intermittent contact. However, due to variations in glove construction and local conditions, a final assessment should be made by the user. A complete encapsulating suit is recommended for heavy exposures.

RESPIRATORY PROTECTION: Use with adequate ventilation. Up to 250 ppm - wear vapour respirator with type K cartridge or air supplied mask meeting the requirements of AS/NZS 1715 and AS/NZS 1716. Greater than 250 ppm - wear air supplied full face mask meeting the requirements of AS/NZS 1715 and AS/NZS 1716.

9. PHYSICAL AND CHEMICAL PROPERTIES

Physical state:	Gas . Liquid under pressure.
Colour:	Colourless
Odour:	Intensely irritating ammoniacal odour.
Odour Threshold:	5-53 ppm.
Molecular Formula:	NH3
Solubility:	Soluble in water. Soluble in alcohol and ether.
Specific Gravity:	0.682 (-33 °C, liquid)
Relative Vapour Density (air=1):	0.6
Vapour Pressure (20 °C):	882 kPa
Flash Point (°C):	Not applicable

Flammability Limits (%):	15.5 - 25
Autoignition Temperature (°C):	669
% Volatile by Volume:	100
Boiling Point/Range (°C):	-33.4
pH:	11.6 (1m solution)
Viscosity:	0.266 cP @-34°C
Freezing Point/Range (°C):	-34.9 (20% solution)

10. STABILITY AND REACTIVITY

Reactivity: Reacts violently with acids. Hygroscopic: absorbs moisture or water from surrounding air.

Chemical stability: Stable under normal ambient and anticipated storage and handling conditions of temperature and pressure. Ammonia dissolves exothermically in water. Can react explosively with chlorine and hypochlorites or other strong oxidising agents. Critical pressure = 11.4 MPa.

Possibility of hazardous reactions: Corrosive to copper , zinc , and their alloys .

Conditions to avoid: Avoid exposure to heat, sources of ignition, and open flame.

Incompatible materials: Incompatible with oxidising agents , boron halides , acids , acid anhydrides , acid chlorides , halogens , interhalogens , heavy metals and their salts , ethylene oxide , acetaldehyde , calcium , hypochlorous acid , silver, acrolein, boron, perchlorates, chlorites, nitrogen tetroxide, sulfur.

Hazardous decomposition products: Hydrogen. Oxides of nitrogen.

11. TOXICOLOGICAL INFORMATION

No adverse health effects expected if the product is handled in accordance with this Safety Data Sheet and the product label. Symptoms or effects that may arise if the product is mishandled and overexposure occurs are:

Ingestion: Not a likely route of exposure, however, swallowing liquid will result in freeze burns of the mouth, throat and stomach.

Eye contact: A severe eye irritant. Corrosive to eyes; contact can cause corneal burns. Contamination of eyes can result in permanent injury. Liquid splashes or spray may cause freeze burns to the eye.

Skin contact: Liquid splashes or spray may cause freeze burns. Contact with skin will result in severe irritation. Corrosive to skin - may cause skin burns.

Inhalation: Material is irritant to the mucous membranes of the respiratory tract (airways). Exposure to concentrations above the Exposure Standard of 25 ppm may cause irritation to the eyes, nose and throat. Higher concentrations may cause breathing difficulty, chest pain, bronchospasm, pink frothy sputum and pulmonary oedema. This may further predispose the patient to the development of acute bronchitis and pneumonia. Overexposure may result in death.

Acute toxicity:
Oral LD50 (rat): 350 mg/kg

Inhalation LC50 (rat): 2000 ppm/4hr

Skin corrosion/irritation: Irritant (human).
Serious eye damage/irritation: Severe irritant (human).
Chronic effects: Chronic exposure to ammonia may cause chemical pneumonitis and kidney damage.

Ammonia: Lowest Published Lethal Concentration (human) = 5,000 ppm/5 min.

Irritation of the respiratory tract and conjunctivae was found in workers inhaling 100 ppm ammonia and 20 ppm caused complaints and discomfort to unacclimatitised workers.

Studies on the effect on man of exposures in the 5-50 ppm range are few, however general field experience in a large number of workers exposed to ammonia from blueprinting and copying machines indicates a maximum acceptable concentration without severe complaints of 20-25 ppm.

12. ECOLOGICAL INFORMATION

Ecotoxicity Avoid contaminating waterways.

Persistence/degradability: The material is biodegradable. Ammonia is strongly adsorbed to soil and sediment particles and colloids in water.

Aquatic toxicity: Very toxic to aquatic organisms. Ammonia is readily oxidised to nitrite which is also very toxic to fish.
24hr LC50 (rainbow trout - fertilized egg) = >3.58 mg/L.
24hr LC50 (rainbow trout - alevins 0-50 days old) = >3.58 mg/L.
24hr LC50 (rainbow trout - fry 85 days old) = 0.068 mg/L.
24hr LC50 (rainbow trout - adult): 0.097 mg/L.

48hr LC50 (Daphnia magna): 24 - 189 mg/L.
96hr LC50 (rainbow trout): 0.53 mg/L.
Terrestrial toxicity: Expected to be harmful to terrestrial species.

13. DISPOSAL CONSIDERATIONS

Disposal methods:
Refer to Waste Management Authority. Close valves of empty containers. Return empty containers to supplier using the same precautions as with filled containers.

14. TRANSPORT INFORMATION

Road and Rail Transport
Classified as Dangerous Goods by the criteria of the Australian Dangerous Goods Code (ADG Code) for Transport by Road and Rail; DANGEROUS GOODS.

UN No: 1005
Transport Hazard Class: 2.3 Toxic Gas
Subrisk 1: 8 Corrosive

Proper Shipping Name or Technical Name:	AMMONIA, ANHYDROUS
Hazchem or Emergency Action Code:	2RE

Marine Transport

Classified as Dangerous Goods by the criteria of the International Maritime Dangerous Goods Code (IMDG Code) for transport by sea; DANGEROUS GOODS.

UN No:	1005
Transport Hazard Class:	2.3 Toxic Gas
Subrisk 1:	8 Corrosive
Proper Shipping Name or Technical Name:	AMMONIA, ANHYDROUS
IMDG EMS Fire:	F-C
IMDG EMS Spill:	S-U
Marine Pollutant	Yes

Air Transport

Classified as Dangerous Goods by the criteria of the International Air Transport Association (IATA) Dangerous Goods Regulations for transport by air; DANGEROUS GOODS.
TRANSPORT PROHIBITED under the International Air Transport Association (IATA) Dangerous Goods Regulations for transport by air in Passenger and Cargo Aircraft, and Cargo Aircraft Only.

UN No:	1005
Transport Hazard Class:	2.3 Toxic Gas
Subrisk 1:	8 Corrosive
Proper Shipping Name or Technical Name:	AMMONIA, ANHYDROUS

15. REGULATORY INFORMATION

Classification:
This material is hazardous according to Safe Work Australia; HAZARDOUS CHEMICAL.

Classification of the chemical:
Flammable Gases - Category 2
Gases under pressure - Liquefied Gas
Acute Inhalation Toxicity - Category 3
Skin Corrosion - Sub-category 1B
Eye Damage - Category 1
Specific target organ toxicity (single exposure) - Category 3

The following health/environmental hazard categories fall outside the scope of the Workplace Health and Safety Regulations:
Acute Aquatic Toxicity - Category 1

Hazard Statement(s):
H221 Flammable gas.
H280 Contains gas under pressure; may explode if heated.
H314 Causes severe skin burns and eye damage.
H331 Toxic if inhaled.
H335 May cause respiratory irritation.

Poisons Schedule (SUSMP): S6 Poison.

This material is listed on the Australian Inventory of Chemical Substances (AICS).

16. OTHER INFORMATION

BIBRA Toxicity Profile - Ammonia 1986. Orica Chemicals Handbook Ammonia. Orica Australia Operations Pty. Ltd. 1993. In: 'Quick Selection Guide to Chemical Protective Clothing'. 3rd Edition. Eds. Forsberg, K. and Mansdon, S.Z. Van Nostrand Reinhold, New York, 1997.
Canadian Centre for Occupational Health and Safety - Web Info Service. 2001.
In: 'The Dictionary of Substances and their Effects'. Ed.Gangolli S. Royal Society of Chemistry, 1999.
In: `Handbook of Environmental Data on Organic Chemicals'. 3rd Edition. Ed. Verschueren. Van Nostrand Reinhold Company, New York 1996.
Supplier Safety Data Sheet; 03/ 2014.

This safety data sheet has been prepared by Ixom Operations Pty Ltd Toxicology & SDS Services.

Reason(s) for Issue:
5 Yearly Revised Primary SDS
Change in Stability and Reactivity

This SDS summarises to our best knowledge at the date of issue, the chemical health and safety hazards of the material and general guidance on how to safely handle the material in the workplace. Since Ixom Operations Pty Ltd cannot anticipate or control the conditions under which the product may be used, each user must, prior to usage, assess and control the risks arising from its use of the material.

If clarification or further information is needed, the user should contact their Ixom representative or Ixom Operations Pty Ltd at the contact details on page 1.

Ixom Operations Pty Ltd's responsibility for the material as sold is subject to the terms and conditions of sale, a copy of which is available upon request.

Safety Data Sheet

1. IDENTIFICATION OF THE MATERIAL AND SUPPLIER

Product Name:	**HYDROGEN CYANIDE GAS**
Other name(s):	Hydrogen cyanide gas (decomposition product of sodium cyanide); Hydrocyanic acid gas.
Recommended Use of the Chemical and Restrictions on Use	Decomposition product of sodium cyanide.
Supplier:	Ixom Operations Pty Ltd
ABN:	51 600 546 512
Street Address:	Level 8, 1 Nicholson Street Melbourne 3000 Australia
Telephone Number:	+61 3 9665 7111
Facsimile:	+61 3 9665 7937
Emergency Telephone:	**1 800 033 111 (ALL HOURS)**

Please ensure you refer to the limitations of this Safety Data Sheet as set out in the "Other Information" section at the end of this Data Sheet.

2. HAZARDS IDENTIFICATION

Classified as Dangerous Goods by the criteria of the Australian Dangerous Goods Code (ADG Code) for Transport by Road and Rail; DANGEROUS GOODS.

This material is hazardous according to Safe Work Australia; HAZARDOUS SUBSTANCE.

Classification of the substance or mixture:
Flammable liquids - Category 1
Acute Oral Toxicity - Category 1
Acute Dermal Toxicity - Category 1
Acute Inhalation Toxicity - Category 1
Specific target organ toxicity (single exposure) - Category 1

The following health/environmental hazard categories fall outside the scope of the Workplace Health and Safety Regulations:
Acute Aquatic Toxicity - Category 1
Chronic Aquatic Toxicity - Category 1

SIGNAL WORD: DANGER

Hazard Statement(s):
H224 Extremely flammable liquid and vapour.
H300+H310+H330 Fatal if swallowed, in contact with skin or if inhaled.
H370 Causes damage to organs.

Precautionary Statement(s):

Prevention:
P210 Keep away from heat / sparks / open flames / hot surfaces. No smoking.
P233 Keep container tightly closed.
P240 Ground / bond container and receiving equipment.
P241 Use explosion-proof electrical / ventilating / lighting equipment.
P242 Use only non-sparking tools.
P243 Take precautionary measures against static discharge.
P260 Do not breathe mist / vapours / spray.
P264 Wash hands thoroughly after handling.
P270 Do not eat, drink or smoke when using this product.
P271 Use only outdoors or in a well-ventilated area.
P280 Wear protective gloves / protective clothing / eye protection / face protection.
P284 Wear respiratory protection.

Response:
P301+P310 IF SWALLOWED: Immediately call a POISON CENTER or doctor/physician.
P330 Rinse mouth.
P302+P350 IF ON SKIN: Gently wash with plenty of soap and water.
P303+P361+P353 IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower.
P310 Immediately call a POISON CENTER or doctor/physician.
P320 Specific treatment is urgent (see First Aid Measures on this Safety Data Sheet).
P322 Specific measures (see First Aid Measures on Safety Data Sheet).
P361 Take off immediately all contaminated clothing.
P363 Wash contaminated clothing before re-use.
P304+P340 IF INHALED: Remove person to fresh air and keep comfortable for breathing.
P307+P311 IF exposed: Call a POISON CENTER or doctor/physician.
P314 Get medical advice/attention if you feel unwell.
P370+P378 In case of fire: Use extinguishing media as outlined in Section 5 of this Safety Data Sheet to extinguish.

Storage:
P403+P233 Store in a well-ventilated place. Keep container tightly closed.
P403+P235 Store in a well-ventilated place. Keep cool.
P405 Store locked up.

Disposal:
P501 Dispose of contents/container in accordance with local/regional/national/international regulations.

Poisons Schedule (SUSMP): S7 Dangerous Poison.

3. COMPOSITION AND INFORMATION ON INGREDIENTS

Components	CAS Number	Proportion	Hazard Codes
Hydrogen cyanide	74-90-8	>99.9%	H224 H300 H310 H330 H370 H372 H410
Stabiliser	-	<0.1%	-

4. FIRST AID MEASURES

For advice, contact a Poisons Information Centre (e.g. phone Australia 131 126; New Zealand 0800 764 766) or a doctor at once. Urgent hospital treatment is likely to be needed.

May be fatal if inhaled, swallowed or absorbed through skin. At all places where there is a risk of cyanide poisoning, items to facilitate the prompt and effective treatment of cyanide poisoning (as determined by the treatment protocol to be employed) should be kept in an accessible and convenient location.

Recommended items include:

- An oxygen resuscitator and a source of oxygen and a clearly marked CYANIDE ANTIDOTE box containing:
- An approved airway, elasticised tourniquet, 5 mL sterile disposable syringe and needles for blood samples, fluoride heparinised blood sample tubes, skin prep swabs, dressing and adhesive tape
-Either:
- 2 Cyanokits containing hydroxocobalamin 5g x 2 amps and the prescribing information outlining side effects and precautions OR
- 2 Ampoules of Kelocyanor (Dicobalt edetate), including the prescribing information outlining side effects and precautions
- Intravenous injection equipment
- A copy of the appropriate Safety Data Sheet and
- A written copy of the relevant treatment protocol

Protect the rescuer

Prior to any attempt at rescue, an assessment of the dangers must be undertaken and measures including the use of appropriate personal protective equipment must be applied to protect the rescuer. Personal protective equipment may include:

- Protective gloves to avoid contact with contaminated skin, clothing and equipment
- Chemical goggles to protect the eyes
- Suitable respiratory protective equipment to prevent inhalation of sodium cyanide dust.

Inhalation:
Shout and send for help.
Remove the person from the source of exposure and ideally to a source of fresh air.
Look for verbal and physical responses from the person suffering from poisoning. Check that they are breathing.
If Patient is Breathing: Oxygen, preferably 100% oxygen if available, should be administered by a qualified person. If the person has collapsed or is unconscious, lie on their side, ensuring airway is clear and open.
If Patient is not Breathing: Ensure airway is clear and open and commence resuscitation using a resuscitation bag or mask connected to an oxygen source (or 100% oxygen via a non rebreathing facemask). Do not use mouth-to-mouth resuscitation. Oxygen, preferably 100% oxygen if available, should be administered by a qualified person. Check for pulse. If pulse is absent start external cardiac massage.

Transport promptly to hospital or medical centre.

Skin Contact:
If skin or hair contact occurs, immediately remove any contaminated clothing and place in a sealed bag for decontamination or disposal. Wash skin and hair thoroughly with running water. Transport promptly to hospital or medical centre. Treat as for 'Inhaled'.

Eye Contact:
Immediately wash in and around the eye area with large amounts of water for at least 15 minutes. Eyelids to be held apart. Remove clothing if contaminated and wash skin. Urgently seek medical assistance. Transport promptly to hospital or medical centre. Treat as for 'Inhaled'.

Indication of immediate medical attention and special treatment needed:
Be certain that victims have been decontaminated properly. Victims who have undergone decontamination pose no serious risks of secondary contamination to rescuers or medical staff treating the victim. In such cases, Support Zone personnel require no specialized protective gear.

Upon presentation, immediately assess the need or otherwise for assisted ventilation, administer 100% oxygen, insert intravenous lines and institute cardiac and blood pressure monitoring if available.

Assess and monitor level of consciousness.

Obtain arterial/venous blood gas as metabolic acidosis, often severe, combined with a small difference between the arterial and venous oxygen saturation levels (<10 mmHg) suggests cyanide poisoning: Correct any severe metabolic acidosis (pH below 7.20) and concurrent electrolyte imbalances (for example, hyperkalaemia, hypercalcaemia).

Take a blood sample in a fluoride heparinised tube for analysis of blood cyanide levels to confirm poisoning, but do not delay treatment while awaiting results. Treatment decisions must be made on clinical grounds.

Symptoms of fear and anxiety about possible cyanide poisoning may mimic those of mild, or the early stages, of cyanide poisoning. It is therefore important to establish cyanide poisoning has actually occurred before administering an antidote as some cyanide antidotes have severe side effects if administered in the absence of cyanide poisoning or if the dose is too great.

If a history of exposure to cyanide has been confirmed and the patient presents with, or develops, severe symptoms of cyanide poisoning (particularly if the patient has lost consciousness, is lapsing into unconsciousness or enters cardiac arrest) then antidote administration may be required.

Antidotes

There are two main antidotes for severe cyanide poisoning

- Hydroxocobalamin (preferred) OR
- Dicobalt edetate (Kelocyanor)

Hydroxocobalamin

Reconstitute the hydroxocobalamin by diluting one flask (5g) of the freeze-dried with 200mL of 0.9% saline and shake rigorously. Administer 5 grams of reconstituted solution via a fast intravenous drip over 15 minutes (approximately 15mL/ min). A further (5g) dose may be given if necessary at a slower rate of infusion - 30 min - 2 hours (or alternatively I.V. sodium thiosulphate 12.5g (50mL) may be given by slow intravenous injection) through a separate IV line . Hydroxocobalamin should not be administered if person has known hypersensitivity to Vitamin B12.

Dicobalt edetate (Kelocyanor)

Note: Overzealous administration of the antidote is contraindicated and may result in serious adverse reactions of an anaphylactic (allergic) nature. Adverse reactions reported include gross oedema of the face and neck, urticaria, palpitations, hypotension, convulsions, vomiting, chest pains, difficulty in breathing, and collapse.

Administer one ampoule containing 300mg Dicobalt edetate in 20mL glucose solution (Kelocyanor) intravenously by slow injection. The initial effect is a fall in blood pressure, rise in pulse rate, and sometimes retching. Immediately after this phase, lasting about one minute, the patient should recover. The injection should be discontinued if allergic adverse effects are noted. A second dose may be given if the response is inadequate and allergic adverse effects have not been observed (or alternatively I.V. sodium thiosulphate 12.5g (50mL) may be given by slow intravenous injection through a separate IV line.

If cyanide has been swallowed, gastric lavage, charcoal and cathartics may be used after antidote treatment if less than two hours have elapsed since ingestion if recommended by an appropriately qualified specialist physician in a specific case although the effectiveness of this measure is not strongly supported by evidence.

Cases of proven and symptomatic cyanide poisoning should be monitored for at least 24 hours and longer if antidote administration had been required for severe poisoning. Eye splashes should be assessed by an ophthalmologist within 24 hours (as cyanide is a severe eye irritant). Persons without symptoms but with significant areas of skin contact should be observed for at least 6 hours to ensure there are no delayed effects.

5. FIRE FIGHTING MEASURES

Suitable Extinguishing Media:
Dry agent (dry chemical powder).

Unsuitable Extinguishing Media:
Carbon dioxide.

Hazchem or Emergency Action Code: 2WE

Specific hazards arising from the substance or mixture:
Extremely flammable. Toxic substance.

Special protective equipment and precautions for fire-fighters:
Fire fighters to wear self-contained breathing apparatus and suitable protective clothing if risk of exposure to vapour or products of combustion.

6. ACCIDENTAL RELEASE MEASURES

Emergency procedures/Environmental precautions:
Clear area of all unprotected personnel. Shut off all possible sources of ignition. If contamination of sewers or waterways has occurred advise local emergency services. For large spills notify the Emergency Services.

Personal precautions/Protective equipment/Methods and materials for containment and cleaning up:
Clear area of all unprotected personnel. Wear protective equipment to prevent skin and eye contact and breathing in vapours/dust.

7. HANDLING AND STORAGE

This material is a Scheduled Poison S7 and must be stored, maintained and used in accordance with the relevant regulations.

Precautions for safe handling:
Extremely flammable - eliminate all potential ignition sources. Keep out of reach of children.

Conditions for safe storage, including any incompatibilities:
Not applicable.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Hydrogen cyanide: Peak Limitation = 11 mg/m^3 (10 ppm), Sk
Cyanides (as CN): 8hr TWA = 5 mg/m^3, Sk

As published by Safe Work Australia Workplace Exposure Standards for Airborne Contaminants.

TWA - The time-weighted average airborne concentration of a particular substance when calculated over an eight-hour working day, for a five-day working week.

`Sk' (skin) Notice - absorption through the skin may be a significant source of exposure. The exposure standard is invalidated if such contact should occur.

Peak Limitation - a maximum or peak airborne concentration of a particular substance determined over the shortest analytically practicable period of time which does not exceed 15 minutes.

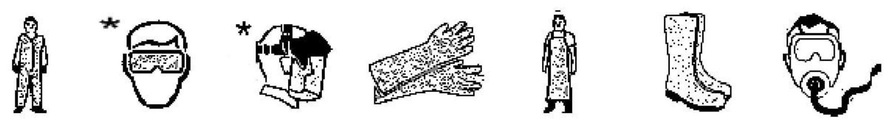
These Workplace Exposure Standards are guides to be used in the control of occupational health hazards. All atmospheric contamination should be kept to as low a level as is workable. These workplace exposure standards should not be used as fine dividing lines between safe and dangerous concentrations of chemicals. They are not a measure of relative toxicity.

Appropriate engineering controls:
Ensure ventilation is adequate to maintain air concentrations below Workplace Exposure Standards.

If in the handling and application of this material, safe exposure levels could be exceeded, the use of engineering controls such as local exhaust ventilation must be considered and the results documented. If achieving safe exposure levels does not require engineering controls, then a detailed and documented risk assessment using the relevant Orica Personal Protection Guide information (refer to PPE section below) as a basis must be carried out to determine the minimum PPE requirements.

Individual protection measures, such as Personal Protective Equipment (PPE):
The selection of PPE is dependent on a detailed risk assessment. The risk assessment should consider the work situation, the physical form of the chemical, the handling methods, and environmental factors.

OVERALLS, CHEMICAL GOGGLES, RUBBER BOOTS, AIR MASK , GLOVES (Long), APRON.
* Not required if wearing air supplied mask.



Wear overalls, chemical goggles, full face shield, elbow-length impervious gloves, splash apron or equivalent chemical impervious outer garment, and rubber boots. Use with adequate ventilation. If determined by a risk assessment an inhalation risk exists, wear an air-supplied mask meeting the requirements of AS/NZS 1715 and AS/NZS 1716. Always wash hands before smoking, eating, drinking or using the toilet. Wash contaminated clothing and other protective equipment before storage or re-use.

9. PHYSICAL AND CHEMICAL PROPERTIES

Physical state:	Gas
Colour:	Colourless
Odour:	Distinctive 'Bitter almonds'
Molecular Formula:	HCN
Solubility:	Soluble in water.
Specific Gravity:	0.938 g/L
Relative Vapour Density (air=1):	0.93 @26°C

Vapour Pressure (20 °C):	62 kPa
Flash Point (°C):	-17.8 (CC)
Flammability Limits (%):	6-41
Autoignition Temperature (°C):	538
% Volatile by Volume:	100
Boiling Point/Range (°C):	Not applicable
pH:	Not applicable

10. STABILITY AND REACTIVITY

Reactivity:	Reacts with oxidising agents.
Chemical stability:	No information available.
Possibility of hazardous reactions:	If not stabilised, can polymerise violently.
Conditions to avoid:	Avoid exposure to heat, sources of ignition, and open flame.
Incompatible materials:	Incompatible with oxidising agents .
Hazardous decomposition products:	Cyanides.

11. TOXICOLOGICAL INFORMATION

No adverse health effects expected if the product is handled in accordance with this Safety Data Sheet and the product label. Symptoms or effects that may arise if the product is mishandled and overexposure occurs are:

Ingestion:	Swallowing can result in nausea, vomiting, diarrhoea, abdominal pain, convulsions and loss of consciousness. Collapse and possible death may occur.
Eye contact:	May be an eye irritant.
Skin contact:	Contact with skin may result in irritation. Can be absorbed through the skin. Effects can include those described for 'INGESTION'.
Inhalation:	Breathing in high concentrations may result in the same symptoms described for 'INGESTION'. High inhaled concentrations may lead to a feeling of suffocation and cause difficulty in breathing, headaches, dizziness and loss of consciousness. Can cause suffocation.

Acute toxicity:
Oral LD50 (mice): 3700 ug/kg

Chronic effects: Repeated or prolonged skin contact may lead to irritant contact dermatitis - 'cyanide rash' - characterised by itching and skin eruptions. Chronic and subchronic exposure to cyanide is known to induce thyroid effects due to the cyanide metabolite, thiocyanate. Thiocyanate adversely affects the thyroid gland via competitive inhibition of iodide uptake and perturbation of the homeostatic feedback mechanisms that regulate the synthesis and secretion of essential thyroid hormones.

12. ECOLOGICAL INFORMATION

Ecotoxicity	Avoid contaminating waterways.

Aquatic toxicity: Very toxic to aquatic organisms. May cause long term adverse effects in the aquatic environment.

13. DISPOSAL CONSIDERATIONS

Disposal methods:
Refer to Waste Management Authority. Waste treatment is essential.

14. TRANSPORT INFORMATION

Road and Rail Transport
Classified as Dangerous Goods by the criteria of the Australian Dangerous Goods Code (ADG Code) for Transport by Road and Rail; DANGEROUS GOODS.

UN No:	1051
Transport Hazard Class:	6.1 Toxic
Subrisk 1:	3 Flammable Liquid
Packing Group:	I
Proper Shipping Name or Technical Name:	HYDROGEN CYANIDE, STABILIZED
Hazchem or Emergency Action Code:	2WE

Marine Transport
Classified as Dangerous Goods by the criteria of the International Maritime Dangerous Goods Code (IMDG Code) for transport by sea; DANGEROUS GOODS.

UN No:	1051
Transport Hazard Class:	6.1 Toxic
Subrisk 1:	3 Flammable liquid
Packing Group:	I
Proper Shipping Name or Technical Name:	HYDROGEN CYANIDE, STABILIZED
IMDG EMS Fire:	F-E
IMDG EMS Spill:	S-D
Marine Pollutant	Yes

Air Transport
Classified as Dangerous Goods by the criteria of the International Air Transport Association (IATA) Dangerous Goods Regulations for transport by air; DANGEROUS GOODS.
TRANSPORT PROHIBITED under the International Air Transport Association (IATA) Dangerous Goods Regulations for transport by air in Passenger and Cargo Aircraft, and Cargo Aircraft Only.

UN No:	1051
Transport Hazard Class:	6.1 Toxic
Subrisk 1:	3 Flammable Liquid
Packing Group:	I
Proper Shipping Name or Technical Name:	HYDROGEN CYANIDE, STABILIZED

Special precautions for user: Hydrogen cyanide (HCN) gas is a decomposition product of sodium cyanide. The above dangerous goods classification indicates that HCN is a compressed gas and could be present as a liquid. HCN liquid nor HCN compressed gas are sold or used by Ixom Operations Pty Ltd.

15. REGULATORY INFORMATION

Classification:
This material is hazardous according to Safe Work Australia; HAZARDOUS SUBSTANCE.

Classification of the substance or mixture:
Flammable liquids - Category 1
Acute Oral Toxicity - Category 1
Acute Dermal Toxicity - Category 1
Acute Inhalation Toxicity - Category 1
Specific target organ toxicity (single exposure) - Category 1

The following health/environmental hazard categories fall outside the scope of the Workplace Health and Safety Regulations:
Acute Aquatic Toxicity - Category 1
Chronic Aquatic Toxicity - Category 1

Hazard Statement(s):
H224 Extremely flammable liquid and vapour.
H300+H310+H330 Fatal if swallowed, in contact with skin or if inhaled.
H370 Causes damage to organs.

Poisons Schedule (SUSMP): S7 Dangerous Poison.

This material is listed on the Australian Inventory of Chemical Substances (AICS).

16. OTHER INFORMATION

Worksafe Australia Cyanide Poisoning; National Occupational Health and Safety Commission; Australian Government Publishing Service, 1989.
`Registry of Toxic Effects of Chemical Substances'. Ed. D. Sweet, US Dept. of Health & Human Services: Cincinatti, 2014.
US EPA Tox review of HCN and CN-salts 2010-09.

This safety data sheet has been prepared by Ixom Operations Pty Ltd Toxicology & SDS Services.

Reason(s) for Issue:
Change in company details

This SDS summarises to our best knowledge at the date of issue, the chemical health and safety hazards of the material and general guidance on how to safely handle the material in the workplace. Since Ixom Operations Pty Ltd cannot anticipate or control the conditions under which the product may be used, each user must, prior to usage, assess and control the risks arising from its use of the material.

If clarification or further information is needed, the user should contact their Ixom representative or Ixom Operations Pty Ltd at the contact details on page 1.

Ixom Operations Pty Ltd's responsibility for the material as sold is subject to the terms and conditions of sale, a copy of which is available upon request.

SAFETY DATA SHEET

Version 4.14
Revision Date 09/22/2017
Print Date 04/13/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name	:	Sodium cyanide
Product Number	:	380970
Brand	:	Sigma-Aldrich
Index-No.	:	006-007-00-5
CAS-No.	:	143-33-9

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses	:	Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company	:	Sigma-Aldrich 3050 Spruce Street SAINT LOUIS MO 63103 USA
Telephone	:	+1 800-325-5832
Fax	:	+1 800-325-5052

1.4 Emergency telephone number

Emergency Phone #	:	+1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Corrosive to metals (Category 1), H290
Acute toxicity, Oral (Category 1), H300
Acute toxicity, Inhalation (Category 1), H330
Acute toxicity, Dermal (Category 1), H310
Specific target organ toxicity - repeated exposure (Category 1), H372
Acute aquatic toxicity (Category 1), H400
Chronic aquatic toxicity (Category 1), H410

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word: Danger

Hazard statement(s)

H290	May be corrosive to metals.
H300 + H310 + H330	Fatal if swallowed, in contact with skin or if inhaled
H372	Causes damage to organs through prolonged or repeated exposure.
H410	Very toxic to aquatic life with long lasting effects.

Precautionary statement(s)

P234	Keep only in original container.
P260	Do not breathe dust/ fume/ gas/ mist/ vapours/ spray.

P262	Do not get in eyes, on skin, or on clothing.
P264	Wash skin thoroughly after handling.
P270	Do not eat, drink or smoke when using this product.
P271	Use only outdoors or in a well-ventilated area.
P273	Avoid release to the environment.
P280	Wear protective gloves/ protective clothing.
P284	Wear respiratory protection.
P301 + P310 + P330	IF SWALLOWED: Immediately call a POISON CENTER/doctor. Rinse mouth.
P302 + P350 + P310	IF ON SKIN: Gently wash with plenty of soap and water. Immediately call a POISON CENTER or doctor/ physician.
P304 + P340 + P310	IF INHALED: Remove person to fresh air and keep comfortable for breathing. Immediately call a POISON CENTER/doctor.
P314	Get medical advice/ attention if you feel unwell.
P362	Take off contaminated clothing and wash before reuse.
P390	Absorb spillage to prevent material damage.
P391	Collect spillage.
P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
P405	Store locked up.
P406	Store in corrosive resistant stainless steel container with a resistant inner liner.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS

Contact with acids liberates very toxic gas.

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	CNNa
Molecular weight	:	49.01 g/mol
CAS-No.	:	143-33-9
EC-No.	:	205-599-4
Index-No.	:	006-007-00-5

Hazardous components

Component	Classification	Concentration
Sodium cyanide		
	Met. Corr. 1; Acute Tox. 1; STOT RE 1; Aquatic Acute 1; Aquatic Chronic 1; H290, H300 + H310 + H330, H372, H410	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice

Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled

If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact

Wash off with soap and plenty of water. Take victim immediately to hospital. Consult a physician.

In case of eye contact

Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Dry powder

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Wear respiratory protection. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas. Avoid breathing dust.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Do not flush with water. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid formation of dust and aerosols.Further processing of solid materials may result in the formation of combustible dusts. The potential for combustible dust formation should be taken into consideration before additional processing occurs.
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.
Never allow product to get in contact with water during storage. Do not store near acids.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Sodium cyanide	143-33-9	TWA	5.000000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
	Remarks	CAS number varies with compound Skin designation		
		C	5.000000 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
		Upper Respiratory Tract irritation Headache Nausea Thyroid effects Danger of cutaneous absorption varies		
		C	4.700000 ppm 5.000000 mg/m3	USA. NIOSH Recommended Exposure Limits
		10 minute ceiling value		
		C	5.000000 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
		Upper Respiratory Tract irritation Headache Nausea Thyroid effects Danger of cutaneous absorption varies		
		C	4.7 ppm 5 mg/m3	USA. NIOSH Recommended Exposure Limits
		10 minute ceiling value		
		TWA	5 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		CAS number varies with compound Skin designation		
		C	5 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
		Upper Respiratory Tract irritation Headache Nausea Thyroid effects Danger of cutaneous absorption varies		
		PEL	5 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)
		Skin		

8.2 Exposure controls

Appropriate engineering controls
Avoid contact with skin, eyes and clothing. Wash hands before breaks and immediately after handling the product.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face particle respirator type N100 (US) or type P3 (EN 143) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: crystalline Colour: white
b)	Odour	odourless
c)	Odour Threshold	No data available
d)	pH	11.0 - 12.0 at 49.0 g/l at 25 °C (77 °F)
e)	Melting point/freezing point	Melting point/range: 563.7 °C (1,046.7 °F) - lit.
f)	Initial boiling point and boiling range	1,500 °C (2,732 °F) at 1.013 hPa (0.760 mmHg)
g)	Flash point	No data available
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	1 hPa (1 mmHg) at 817 °C (1,503 °F)
l)	Vapour density	No data available
m)	Relative density	1.59 kg/m3 at 20 °C (68 °F)
n)	Water solubility	ca.49 g/l at 20 °C (68 °F) - soluble
o)	Partition coefficient: n-octanol/water	No data available

p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Do not store near acids., Strong oxidizing agents, Carbon dioxide (CO2)

10.6 Hazardous decomposition products
Other decomposition products - No data available
Hazardous decomposition products formed under fire conditions. - Carbon oxides, Sodium oxides
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - 4.7 mg/kg
Remarks: Behavioral:Tetany. Behavioral:Ataxia. Lungs, Thorax, or Respiration:Respiratory obstruction.

Inhalation: No data available

LD50 Dermal - Rabbit - 10.4 mg/kg
Remarks: Behavioral:Somnolence (general depressed activity). Behavioral:Tremor. Lungs, Thorax, or Respiration:Dyspnea.

LD50 Intramuscular - Rabbit - 1.666 mg/kg

LD50 Intraperitoneal - Rat - 4.3 mg/kg

LD50 Intraperitoneal - Mouse - 4.9 mg/kg

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
Ames test
Salmonella typhimurium
Result: negative

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity

Reproductive toxicity - Rat - Oral
Paternal Effects: Spermatogenesis (including genetic material, sperm morphology,motility, and count). Paternal Effects: Testes, epididymis, sperm duct.

Reproductive toxicity - Hamster - Implant
Effects on Fertility: Post-implantation mortality (e.g., dead and/or resorbed implants per total number of implants). Specific Developmental Abnormalities: Central nervous system.

Developmental Toxicity - Hamster - Implant
Effects on Embryo or Fetus: Fetotoxicity (except death, e.g., stunted fetus). Specific Developmental Abnormalities: Musculoskeletal system. Specific Developmental Abnormalities: Cardiovascular (circulatory) system.

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: VZ7525000

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

Stomach - Irregularities - Based on Human Evidence
Stomach - Irregularities - Based on Human Evidence

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish	static test LC50 - Tilapia mossambica - 0.04 mg/l - 96 h
Toxicity to daphnia and other aquatic invertebrates	LC50 - Daphnia magna (Water flea) - 0.09 mg/l - 96 h
Toxicity to algae	EC50 - Nitzschia closterium - 0.051 mg/l - 72 h

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
An environmental hazard cannot be excluded in the event of unprofessional handling or disposal.
Very toxic to aquatic life with long lasting effects.

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product

Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material. Dissolve or mix the material with a combustible solvent and burn in a chemical incinerator equipped with an afterburner and scrubber.

Contaminated packaging

Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)

UN number: 1689 Class: 6.1 Packing group: I
Proper shipping name: Sodium cyanide, solid
Reportable Quantity (RQ): 10 lbs
Poison Inhalation Hazard: No

IMDG

UN number: 1689 Class: 6.1 Packing group: I EMS-No: F-A, S-A
Proper shipping name: SODIUM CYANIDE, SOLID
Marine pollutant: yes

IATA

UN number: 1689 Class: 6.1 Packing group: I
Proper shipping name: Sodium cyanide, solid

15. REGULATORY INFORMATION

SARA 302 Components

The following components are subject to reporting levels established by SARA Title III, Section 302:

	CAS-No.	Revision Date
Sodium cyanide	143-33-9	1993-04-24

SARA 313 Components

The following components are subject to reporting levels established by SARA Title III, Section 313:

	CAS-No.	Revision Date
Sodium cyanide	143-33-9	1993-04-24

SARA 311/312 Hazards

Acute Health Hazard, Chronic Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Sodium cyanide	143-33-9	1993-04-24

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Sodium cyanide	143-33-9	1993-04-24

New Jersey Right To Know Components

	CAS-No.	Revision Date
Sodium cyanide	143-33-9	1993-04-24

California Prop. 65 Components

	CAS-No.	Revision Date
WARNING: This product contains a chemical known to the State of California to cause birth defects or other reproductive harm. Sodium cyanide	143-33-9	2013-08-15

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Acute Tox.	Acute toxicity
Aquatic Acute	Acute aquatic toxicity
Aquatic Chronic	Chronic aquatic toxicity
H290	May be corrosive to metals.
H300	Fatal if swallowed.
H300 + H310 + H330	Fatal if swallowed, in contact with skin or if inhaled
H310	Fatal in contact with skin.
H330	Fatal if inhaled.
H372	Causes damage to organs through prolonged or repeated exposure.
H400	Very toxic to aquatic life.

HMIS Rating

Health hazard:	4
Chronic Health Hazard:	*
Flammability:	0
Physical Hazard	0

NFPA Rating

Health hazard:	4
Fire Hazard:	0
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.14 Revision Date: 09/22/2017 Print Date: 04/13/2018

SAFETY DATA SHEET

Version 5.9
Revision Date 09/21/2017
Print Date 04/13/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name	:	Potassium cyanide
Product Number	:	207810
Brand	:	Sigma-Aldrich
Index-No.	:	006-007-00-5
CAS-No.	:	151-50-8

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company	:	Sigma-Aldrich 3050 Spruce Street SAINT LOUIS MO 63103 USA
Telephone	:	+1 800-325-5832
Fax	:	+1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Corrosive to metals (Category 1), H290
Acute toxicity, Oral (Category 1), H300
Acute toxicity, Inhalation (Category 1), H330
Acute toxicity, Dermal (Category 1), H310
Specific target organ toxicity - single exposure, Oral (Category 1), Heart, Testes, Brain, H370
Specific target organ toxicity - repeated exposure (Category 1), Thyroid, H372
Acute aquatic toxicity (Category 1), H400
Chronic aquatic toxicity (Category 1), H410

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word: Danger

Hazard statement(s)

H290	May be corrosive to metals.
H300 + H310 + H330	Fatal if swallowed, in contact with skin or if inhaled
H370	Causes damage to organs (Heart, Testes, Brain) if swallowed.
H372	Causes damage to organs (Thyroid) through prolonged or repeated exposure.
H410	Very toxic to aquatic life with long lasting effects.

Precautionary statement(s)

P234	Keep only in original container.
P260	Do not breathe dust/ fume/ gas/ mist/ vapours/ spray.
P262	Do not get in eyes, on skin, or on clothing.
P264	Wash skin thoroughly after handling.
P270	Do not eat, drink or smoke when using this product.
P271	Use only outdoors or in a well-ventilated area.
P273	Avoid release to the environment.
P280	Wear protective gloves/ protective clothing.
P284	Wear respiratory protection.
P301 + P310 + P330	IF SWALLOWED: Immediately call a POISON CENTER/doctor. Rinse mouth.
P302 + P350 + P310	IF ON SKIN: Gently wash with plenty of soap and water. Immediately call a POISON CENTER or doctor/ physician.
P304 + P340 + P310	IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing. Immediately call a POISON CENTER or doctor/ physician.
P307 + P311	IF exposed: Call a POISON CENTER or doctor/ physician.
P361	Remove/Take off immediately all contaminated clothing.
P363	Wash contaminated clothing before reuse.
P390	Absorb spillage to prevent material damage.
P391	Collect spillage.
P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
P405	Store locked up.
P406	Store in corrosive resistant stainless steel container with a resistant inner liner.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS

Contact with acids liberates very toxic gas.

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	CKN
Molecular weight	:	65.12 g/mol
CAS-No.	:	151-50-8
EC-No.	:	205-792-3
Index-No.	:	006-007-00-5

Hazardous components

Component	Classification	Concentration
Potassium cyanide		
	Acute Tox. 2; Acute Tox. 1; STOT RE 1; Aquatic Acute 1; Aquatic Chronic 1; H300 + H310 + H330, H372, H410	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice

Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled

If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Take off contaminated clothing and shoes immediately. Wash off with soap and plenty of water. Take victim immediately to hospital. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.Continue rinsing eyes during transport to hospital.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Dry chemical Dry sand Alcohol-resistant foam

Unsuitable extinguishing media
Water Carbon dioxide (CO_2)

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Wear respiratory protection. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas. Avoid breathing dust.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Do not flush with water. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid formation of dust and aerosols.
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.
Never allow product to get in contact with water during storage. Do not store near acids.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Potassium cyanide	151-50-8	C	4.700000 ppm 5.000000 mg/m3	USA. NIOSH Recommended Exposure Limits
	Remarks	10 minute ceiling value		
		TWA	5.000000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		CAS number varies with compound Skin designation		
		C	5.000000 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
		Upper Respiratory Tract irritation Headache Nausea Thyroid effects Danger of cutaneous absorption varies		
		C	5.000000 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
		Upper Respiratory Tract irritation Headache Nausea Thyroid effects Danger of cutaneous absorption varies		
		C	4.7 ppm 5 mg/m3	USA. NIOSH Recommended Exposure Limits
		10 minute ceiling value		
		TWA	5 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		CAS number varies with compound Skin designation		
		C	5 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
		Upper Respiratory Tract irritation Headache Nausea Thyroid effects Danger of cutaneous absorption varies		
		PEL	5 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)
		Skin		

8.2 Exposure controls

Appropriate engineering controls

Avoid contact with skin, eyes and clothing. Wash hands before breaks and immediately after handling the product.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face particle respirator type N100 (US) or type P3 (EN 143) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

---

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: crystalline Colour: white
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	11.5 at 20 g/l at 20 °C (68 °F)
e)	Melting point/freezing point	Melting point/range: 634 °C (1,173 °F) - lit.
f)	Initial boiling point and boiling range	1,625 °C (2,957 °F)
g)	Flash point	No data available
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or	No data available

	explosive limits	
k)	Vapour pressure	No data available
l)	Vapour density	No data available
m)	Relative density	1.520 g/cm3
n)	Water solubility	400 g/l at 20 °C (68 °F) - soluble
o)	Partition coefficient: n-octanol/water	log Pow: 0.44
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
Contact with acids liberates very toxic gas.

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Avoid moisture.

10.5 Incompatible materials
Acids, Strong oxidizing agents, Iodine, permanganates, e.g. potassium permanganate, Peroxides, Metallic salts, Chloral hydrate, Alkaloids, Chlorates

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides, Nitrogen oxides (NOx), Potassium oxides, Hydrogen cyanide (hydrocyanic acid)
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - female - >= 7.49 mg/kg

Inhalation: No data available

LD50 Dermal - Rabbit - female - 14.29 mg/kg

LD50 Intraperitoneal - Rat - 4 mg/kg
Remarks: Lungs, Thorax, or Respiration:Other changes.

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
Hamster
fibroblast
Result: negative

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information

Repeated dose toxicity	Rat - male - Oral - NOAEL : 40 mg/kg

RTECS: TS8750000

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

Lung irritation, Cyanosis, Central nervous system depression, To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated., May cause argyria (a slate-gray or bluish discoloration of the skin and deep tissues due to the deposit of insoluble albuminate of silver)., Material is extremely destructive to tissue of the mucous membranes and upper respiratory tract, eyes, and skin., Inhalation may provoke the following symptoms:, spasm, inflammation and edema of the bronchi, Aspiration or inhalation may cause chemical pneumonitis., pulmonary edema, Lungs, CNS depression with hypertension or circulatory failure, and respiratory depression

Liver - Irregularities - Based on Human Evidence
Liver - Irregularities - Based on Human Evidence

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to daphnia and other aquatic invertebrates	static test EC50 - Daphnia pulex (Water flea) - 0.11 mg/l - 48 h
Toxicity to algae	IC50 - Scenedesmus quadricauda (Green algae) - 0.03 mg/l - 192 h
Toxicity to bacteria	Respiration inhibition - Sludge Treatment - 2.3 mg/l - 30 min

12.2 Persistence and degradability
No data available

Chemical Oxygen Demand (COD)	< 1 mg/g

12.3 Bioaccumulative potential

Bioaccumulation	Oncorhynchus mykiss (rainbow trout) - 16 Weeks - 20.8 µg/l

Bioconcentration factor (BCF): 170

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
An environmental hazard cannot be excluded in the event of unprofessional handling or disposal.
Very toxic to aquatic life with long lasting effects.

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material. Dissolve or mix the material with a combustible solvent and burn in a chemical incinerator equipped with an afterburner and scrubber.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1680 Class: 6.1 Packing group: I
Proper shipping name: Potassium cyanide, solid
Reportable Quantity (RQ): 10 lbs
Poison Inhalation Hazard: No

IMDG
UN number: 1680 Class: 6.1 Packing group: I EMS-No: F-A, S-A
Proper shipping name: POTASSIUM CYANIDE, SOLID
Marine pollutant: yes

IATA
UN number: 1680 Class: 6.1 Packing group: I
Proper shipping name: Potassium cyanide, solid

15. REGULATORY INFORMATION

SARA 302 Components
The following components are subject to reporting levels established by SARA Title III, Section 302:

	CAS-No.	Revision Date
Potassium cyanide	151-50-8	1993-04-24

SARA 313 Components
The following components are subject to reporting levels established by SARA Title III, Section 313:

	CAS-No.	Revision Date
Potassium cyanide	151-50-8	1993-04-24

SARA 311/312 Hazards
Acute Health Hazard, Chronic Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Potassium cyanide	151-50-8	1993-04-24

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Potassium cyanide	151-50-8	1993-04-24

New Jersey Right To Know Components

	CAS-No.	Revision Date
Potassium cyanide	151-50-8	1993-04-24

California Prop. 65 Components

WARNING: This product contains a chemical known to the State of California to cause birth defects or other reproductive harm. Potassium cyanide	CAS-No. 151-50-8	Revision Date 2013-08-15

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Acute Tox.	Acute toxicity
Aquatic Acute	Acute aquatic toxicity
Aquatic Chronic	Chronic aquatic toxicity
H290	May be corrosive to metals.
H300	Fatal if swallowed.
H300 + H310 + H330	Fatal if swallowed, in contact with skin or if inhaled
H310	Fatal in contact with skin.
H330	Fatal if inhaled.

HMIS Rating

Health hazard:	4
Chronic Health Hazard:	*
Flammability:	0
Physical Hazard	0

NFPA Rating

Health hazard:	4
Fire Hazard:	0
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.9   Revision Date: 09/21/2017   Print Date: 04/13/2018

Section 26: Appendix D

Appendix D.1: Input File

```
;

;Input Summary created by Aspen Plus Rel. 36.0 at 20:40:17 Tue Apr 17, 2018
;Directory \\nestor\baylisn\Aspen File-4-17  Filename
C:\Users\baylisn\AppData\Local\Temp\Input file.txt
;


DYNAMICS
    DYNAMICS RESULTS=ON

IN-UNITS ENG SHORT-LENGTH=in

DEF-STREAMS MIXCISLD ALL

SIM-OPTIONS MASS-BAL-CHE=YES ADSCNVG=YES

MODEL-OPTION

DATABANKS 'APV100 ASPENPCD' / 'APV100 AQUEOUS' / 'APV100 SOLIDS' &
         / 'APV100 INORGANIC' / 'APESV100 AP-EOS' /  &
        'NISTV100 NIST-TRC' / 'APV100 PURE36'

PROP-SOURCES 'APV100 ASPENPCD' / 'APV100 AQUEOUS' /  &
        'APV100 SOLIDS' / 'APV100 INORGANIC' / 'APESV100 AP-EOS' &
         / 'NISTV100 NIST-TRC' / 'APV100 PURE36'

COMPONENTS
    CH4 CH4 /
    NH3 H3N /
    CO2 CO2 /
    HCN CHN /
    CO CO /
    H2 H2 /
    O2 O2 /
    N2 N2 /
    H2O H2O /
    NAOH NAOH /
    H3O+ H3O+ /
    NA+ NA+ /
    CN- CN- /
    OH- OH- /
    "NACN(S)" NACN /
    "NAOH:(S)" "NAOH*W" /
    "NAOH(S)" NAOH /
    CO3-- CO3-2 /
    HCO3- HCO3- /
    SODIU-01 NAHCO3 /
    SODIU-02 NA2CO3 /
    AMMON-01 NH6PO4 /
    DIAMM-01 "(NH4)2HPO4" /
    NH4+ NH4+ /
    H2PO4-01 H2PO4- /
    HPO4--01 HPO4-2

CISOLID-COMPS "NACN(S)" "NAOH:(S)" "NAOH(S)" SODIU-01 SODIU-02

HENRY-COMPS GLOBAL CO2 NH3 HCN H2 O2 N2 CH4

MOIST-COMPS H2O
```

```
SOLVE
    RUN-MODE MODE=SIM

CHEMISTRY GLOBAL
    PARAM GAMMA-BASIS=UNSYMMETRIC
    DISS NAOH OH- 1 / NA+ 1
    STOIC 1 HCN -1 / H2O -1 / CN- 1 / H3O+ 1
    STOIC 2 H2O -2 / OH- 1 / H3O+ 1
    K-STOIC 1 A=22.902536 B=-9945.530273 C=0 D=-0.049579
    K-STOIC 2 A=132.89888 B=-13445.900391 C=-22.477301 D=0
    SALT "NAOH:(S)" H2O 1 / OH- 1 / NA+ 1
    SALT "NACN(S)" CN- 1 / NA+ 1
    SALT SODIU-01 HCO3- 1. / NA+ 1.
    SALT SODIU-02 CO3-- 1. / NA+ 2.

FLOWSHEET
    BLOCK R-100 IN=7 OUT=8
    BLOCK V-100 IN=21 11 OUT=12 22
    BLOCK SEP-100 IN=24 OUT=25 26
    BLOCK SEP-101 IN=28 OUT=29 30
    BLOCK P-101 IN=25 OUT=28
    BLOCK MIX2 IN=23 29 OUT=24
    BLOCK E-103 IN=22 OUT=NA2CO3 22-23
    BLOCK E-101 IN=8 OUT=9
    BLOCK E100B IN=9 OUT=10
    BLOCK E-103HX IN=22-23 OUT=23
    BLOCK MIX1 IN=20 1-5 OUT=6
    BLOCK V-102 IN=14-15 19 OUT=20 16
    BLOCK V-101 IN=12 18 OUT=13 14-15
    BLOCK E-100A IN=6 OUT=7
    BLOCK E-105 IN=31 OUT=33 32
    BLOCK E-106 IN=34 OUT=35
    BLOCK E-102 IN=10 OUT=11
    BLOCK P-102 IN=32 OUT=34
    BLOCK SEP-102 IN=30 OUT=VAP 36

PROPERTIES ELECNRTL HENRY-COMPS=GLOBAL CHEMISTRY=GLOBAL  &
        TRUE-COMPS=YES
    PROPERTIES SOLIDS

PROP-DATA HOCETA-1
    IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
        INVERSE-PRES='1/bar' SHORT-LENGTH=mm
    PROP-LIST HOCETA
    BPVAL NH3 CO2 .2000000000
    BPVAL NH3 H2O .2000000000
    BPVAL CO2 CO2 .1600000000
    BPVAL CO2 H2O .3000000000
    BPVAL CO2 NH3 .2000000000
    BPVAL H2O CO2 .3000000000
    BPVAL H2O H2O 1.700000000
    BPVAL H2O NH3 .2000000000

PROP-DATA HENRY-1
    IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
        INVERSE-PRES='1/bar' SHORT-LENGTH=mm
    PROP-LIST HENRY
    BPVAL H2 NH3 14.49873454 -18.73080000 0.0 -.0172000000  &
        -62.28010000 121.0883000 0.0
    BPVAL O2 NH3 8.535074535 0.0 0.0 0.0 19.85000000  &
        19.85000000 0.0
    BPVAL N2 NH3 8.131575535 0.0 0.0 0.0 19.85000000  &
        19.85000000 0.0
    BPVAL NH3 H2O 81.75927454 -1096.810000 -16.56020000  &
```

```
        .0602466000 -.1500000000 99.85000000 0.0
    BPVAL CO2 H2O 159.8650745 -8741.550000 -21.66900000  &
        1.10259000E-3 -.1500000000 79.85000000 0.0
    BPVAL H2 H2O 180.0660745 -6993.510000 -26.31190000  &
        .0150431000 .8500000000 65.85000000 0.0
    BPVAL O2 H2O 144.4080745 -7775.060000 -18.39740000  &
        -9.4435400E-3 .8500000000 74.85000000 0.0
    BPVAL N2 H2O 164.9940745 -8432.770000 -21.55800000  &
        -8.4362400E-3 -.1500000000 72.85000000 0.0
    BPVAL HCN H2O 42.28048454 -8136.775000 0.0 -.0448168700  &
        9.850000000 109.8500000 0.0
    BPVAL CH4 H2O 183.7810745 -9111.670000 -25.03790000  &
        1.43434000E-4 1.850000000 79.85000000 0.0

PROP-DATA NRTL-1
    IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
        INVERSE-PRES='1/bar' SHORT-LENGTH=mm
    PROP-LIST NRTL
    BPVAL NH3 H2O 9.612100000 -3232.815900 .3000000000 0.0 0.0  &
        0.0 10.00000000 91.50000000
    BPVAL H2O NH3 -6.268400000 1525.454300 .3000000000 0.0 0.0  &
        0.0 10.00000000 91.50000000

PROP-DATA VLCLK-1
    IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
        INVERSE-PRES='1/bar' SHORT-LENGTH=mm
    PROP-LIST VLCLK
    BPVAL NA+ OH- -13.79420000 72.92090000
    BPVAL NA+ CO3-- -5.411850000 94.55199000
    BPVAL NA+ HCO3- 23.70637000 30.40776000

PROP-DATA GMELCC-1
    IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
        INVERSE-PRES='1/bar' SHORT-LENGTH=mm
    PROP-LIST GMELCC
    PPVAL CO2 ( H3O+ OH- ) 15.00000000
    PPVAL ( H3O+ OH- ) CO2 -8.000000000
    PPVAL H2O ( H3O+ CN- ) 8.045000000
    PPVAL ( H3O+ CN- ) H2O -4.072000000
    PPVAL H2O ( H3O+ OH- ) 8.045000000
    PPVAL ( H3O+ OH- ) H2O -4.072000000
    PPVAL H2O ( NA+ OH- ) 6.737997000
    PPVAL ( NA+ OH- ) H2O -3.771221000
    PPVAL CO2 ( H3O+ CO3-- ) 15.00000000
    PPVAL ( H3O+ CO3-- ) CO2 -8.000000000
    PPVAL H2O ( H3O+ CO3-- ) 8.045000000
    PPVAL ( H3O+ CO3-- ) H2O -4.072000000
    PPVAL H2O ( NA+ CO3-- ) -4.833000000
    PPVAL ( NA+ CO3-- ) H2O .9770000000
    PPVAL CO2 ( H3O+ HCO3- ) 15.00000000
    PPVAL ( H3O+ HCO3- ) CO2 -8.000000000
    PPVAL H2O ( H3O+ HCO3- ) 8.045000000
    PPVAL ( H3O+ HCO3- ) H2O -4.072000000
    PPVAL H2O ( NA+ HCO3- ) 7.834000000
    PPVAL ( NA+ HCO3- ) H2O -4.031000000

PROP-DATA GMELCD-1
    IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
        INVERSE-PRES='1/bar' SHORT-LENGTH=mm
    PROP-LIST GMELCD
    PPVAL CO2 ( H3O+ OH- ) 0.0
    PPVAL ( H3O+ OH- ) CO2 0.0
    PPVAL H2O ( NA+ OH- ) 1420.242000
    PPVAL ( NA+ OH- ) H2O -471.8202000
```

```
    PPVAL CO2 ( H3O+ CO3-- ) 0.0
    PPVAL ( H3O+ CO3-- ) CO2 0.0
    PPVAL H2O ( NA+ CO3-- ) 4018.400000
    PPVAL ( NA+ CO3-- ) H2O -1547.000000
    PPVAL CO2 ( H3O+ HCO3- ) 0.0
    PPVAL ( H3O+ HCO3- ) CO2 0.0

PROP-DATA GMELCE-1
    IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
        INVERSE-PRES='1/bar' SHORT-LENGTH=mm
    PROP-LIST GMELCE
    PPVAL CO2 ( H3O+ OH- ) 0.0
    PPVAL ( H3O+ OH- ) CO2 0.0
    PPVAL H2O ( NA+ OH- ) 3.013932000
    PPVAL ( NA+ OH- ) H2O 2.136557000
    PPVAL CO2 ( H3O+ CO3-- ) 0.0
    PPVAL ( H3O+ CO3-- ) CO2 0.0
    PPVAL H2O ( NA+ CO3-- ) 88.56000000
    PPVAL ( NA+ CO3-- ) H2O -32.40000000
    PPVAL CO2 ( H3O+ HCO3- ) 0.0
    PPVAL ( H3O+ HCO3- ) CO2 0.0

PROP-DATA GMELCN-1
    IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
        INVERSE-PRES='1/bar' SHORT-LENGTH=mm
    PROP-LIST GMELCN
    PPVAL CO2 ( H3O+ OH- ) .1000000000
    PPVAL H2O ( NA+ OH- ) .2000000000
    PPVAL CO2 ( H3O+ CO3-- ) .1000000000
    PPVAL H2O ( NA+ CO3-- ) .2000000000
    PPVAL CO2 ( H3O+ HCO3- ) .1000000000

DEF-STREAMS MIXCISLD 25 32

STREAM 1-5
    SUBSTREAM MIXED TEMP=77.00000000 PRES=14.69594878
    MOLE-FLOW CH4 590.8388627 / NH3 496.0400899 / O2  &
        767.2086724 / N2 2854.986295 / H2O 30.51197709

STREAM 18
    SUBSTREAM MIXED TEMP=158.0000000 PRES=14.69594878
    MOLE-FLOW H2O 705.4792390 / NH4+ 110.2311311 / H2PO4-01  &
        110.2311311

STREAM 19
    SUBSTREAM MIXED TEMP=392.0000000 PRES=14.69594878  &
        MASS-FLOW=3968.320719
    MOLE-FRAC H2O 1.

STREAM 21
    SUBSTREAM MIXED TEMP=158.0000000 PRES=14.69594878  &
        FREE-WATER=NO NPHASE=1 PHASE=L
    MASS-FLOW H2O 14715.85600 / NAOH 14715.85600

STREAM 31
    SUBSTREAM MIXED TEMP=140.0000000 PRES=17.69594878
    MASS-FLOW O2 15658.33217 / N2 4756.473307 / H2O  &
        2015.025076

BLOCK MIX1 MIXER
    PARAM

BLOCK MIX2 MIXER
    PARAM MAXIT=30 TOL=0.0001
```

```
BLOCK E-103 SEP
    PARAM
    FRAC STREAM=NA2CO3 SUBSTREAM=MIXED COMPS=CH4 NH3 CO2 HCN  &
        CO H2 O2 N2 H2O NAOH H3O+ CN- OH- "NACN(S)"  &
        "NAOH:(S)" "NAOH(S)" CO3-- HCO3- SODIU-01 SODIU-02  &
        FRACS=0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  &
        0. 0. 0.8 0.8 0. 0.
    MOLE-FLOW STREAM=NA2CO3 SUBSTREAM=MIXED COMPS=NA+ FLOWS= &
        7.976390785

BLOCK E-105 SEP
    PARAM
    FRAC STREAM=32 SUBSTREAM=MIXED COMPS=O2 N2 FRACS=1. 1.
    MASS-FLOW STREAM=32 SUBSTREAM=MIXED COMPS=H2O FLOWS= &
        1543.235835
    FLASH-SPECS 33 TEMP=122.0000000 PRES=-3.000000000
    FLASH-SPECS 32 TEMP=122.0000000 PRES=-3.000000000

BLOCK SEP-102 SEP
    PARAM
    MASS-FLOW STREAM=VAP SUBSTREAM=MIXED COMPS=H2O FLOWS= &
        471.7892411

BLOCK E-100A HEATER
    PARAM TEMP=392.0000000 PRES=-3.000000000 DPPARMOPT=NO

BLOCK E-101 HEATER
    PARAM TEMP=600.8000000 PRES=-3.000000000 DPPARMOPT=NO

BLOCK E-102 HEATER
    PARAM TEMP=158.0000000 PRES=14.69594878 DPPARMOPT=NO

BLOCK E-103HX HEATER
    PARAM PRES=14.69594878 DELT=9.000000000 DPPARMOPT=NO

BLOCK E-106 HEATER
    PARAM TEMP=302.0000000 PRES=-3.000000000 DPPARMOPT=NO

BLOCK E100B HEATER
    PARAM PRES=-3.000000000 DUTY=-1.1641213E+7 DPPARMOPT=NO

BLOCK V-100 RADFRAC
    PARAM NSTAGE=2 ALGORITHM=STANDARD MAXOL=25 DAMPING=NONE
    COL-CONFIG CONDENSER=NONE REBOILER=NONE
    FEEDS 21 1 ABOVE-STAGE / 11 2 ON-STAGE
    PRODUCTS 22 2 L / 12 1 V
    P-SPEC 1 14.69594878
    COL-SPECS
    REAC-STAGES 1 2 NACN

BLOCK V-101 RADFRAC
    PARAM NSTAGE=2 ALGORITHM=STANDARD MAXOL=25 DAMPING=NONE
    COL-CONFIG CONDENSER=NONE REBOILER=NONE
    FEEDS 12 2 ON-STAGE / 18 1 ABOVE-STAGE
    PRODUCTS 14-15 2 L / 13 1 V
    P-SPEC 1 14.69594878
    COL-SPECS
    REAC-STAGES 1 2 PHOSFORM

BLOCK V-102 RADFRAC
    PARAM NSTAGE=2 ALGORITHM=STANDARD MAXOL=25 DAMPING=NONE
    COL-CONFIG CONDENSER=NONE REBOILER=NONE
    FEEDS 14-15 1 / 19 2 ON-STAGE
```

```
    PRODUCTS 16 2 L / 20 1 V
    P-SPEC 1 14.69594878
    COL-SPECS
    REAC-STAGES 1 2 PHOSDEC

BLOCK R-100 RSTOIC
    PARAM TEMP=2058.800000 PRES=29.39189755 NPHASE=1 PHASE=V  &
        SERIES=NO HEAT-OF-REAC=YES
    STOIC 1 MIXED NH3 -1. / CH4 -1. / O2 -1.5 / HCN 1. /  &
        H2O 3.
    STOIC 2 MIXED CH4 -1. / H2O -1. / CO 1. / H2 3.
    STOIC 4 MIXED NH3 -4. / O2 -3. / N2 2. / H2O 6.
    STOIC 3 MIXED CH4 -1. / O2 -2. / H2O 2. / CO2 1.
    CONV 1 MIXED NH3 0.6
    CONV 2 MIXED CH4 0.35
    CONV 4 MIXED NH3 0.22
    CONV 3 MIXED CH4 0.036
    HEAT-RXN REACNO=1 CID=CH4 / REACNO=2 CID=CH4 / REACNO=3  &
        CID=CH4 / REACNO=4 CID=NH3
    BLOCK-OPTION FREE-WATER=NO

BLOCK P-101 PUMP
    PARAM PRES=14.50377377

BLOCK P-102 COMPR
    PARAM TYPE=ISENTROPIC DELP=9.000000000 SB-MAXIT=30  &
        SB-TOL=0.0001

BLOCK SEP-100 CRYSTALLIZER
    PARAM OPT-PSD=COPY TEMP=140.0000000 NPHASE=2 SALT="NACN(S)"  &
        SOL-METHOD=CHEMISTRY PROD-RATE=16975.59419 FRAC-RFLOW=0.
    PROPERTIES ELECNRTL HENRY-COMPS=GLOBAL CHEMISTRY=GLOBAL  &
        FREE-WATER=STEAM-TA SOLU-WATER=3 TRUE-COMPS=YES

BLOCK SEP-101 CFUGE
    PARAM TYPE=SOLIDS-SEP PRES=14.69594878
    SOLIDS-SEP SOLID-SPLIT=1. FLUID-SPLIT=0.985  &
        CLASS-CHAR=VELOCITY

EO-CONV-OPTI

CONV-OPTIONS
    WEGSTEIN MAXIT=1000

STREAM-REPOR MOLEFLOW

PROPERTY-REP PCES

REACTIONS NACN REAC-DIST
    REAC-DATA 1
    REAC-DATA 2
    REAC-DATA 3 CONV
    REAC-DATA 4
    STOIC 1 HCN -1. / OH- -1. / CN- 1. / H2O 1.
    STOIC 2 H2O -2. / H3O+ 1. / OH- 1.
    STOIC 3 CO2 -1. / H2O -2. / HCO3- 1. / H3O+ 1.
    STOIC 4 HCO3- -1. / H2O -1. / CO3-- 1. / H3O+ 1.
    CONV 3 CONV-A=0.125 KEY-CID=CO2

REACTIONS PHOSDEC REAC-DIST
    REAC-DATA 1 CONV
    STOIC 1 NH4+ -1. / HPO4--01 -1. / NH3 1. / H2PO4-01  &
        1.
    CONV 1 CONV-A=1. KEY-CID=HPO4--01
```

```
REACTIONS PHOSFORM REAC-DIST
    REAC-DATA 1
    STOIC 1 NH3 -1. / H2PO4-01 -1. / HPO4--01 1. / NH4+  &
        1.

REACTIONS HCN GENERAL
    REAC-DATA 1 NAME=MAIN REAC-CLASS=EQUILIBRIUM
    STOIC 1 MIXED CH4 -1. / NH3 -1. / O2 -1.5 / HCN 1. /  &
        H2O 3.
;
;
;
;
;
```

Appendix D.2: Block Report

```
 BLOCK:  E-100A   MODEL: HEATER
 ------------------------------
   INLET STREAM:          6
   OUTLET STREAM:         7
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           4872.86         4872.86         0.00000
       MASS(LB/HR   )           125317.         125317.        0.232242E-15
       ENTHALPY(BTU/HR  )     -0.381668E+08   -0.265256E+08   -0.305009

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            236967.      LB/HR
    PRODUCT STREAMS CO2E         236967.      LB/HR
    NET STREAMS CO2E PRODUCTION  0.00000      LB/HR
    UTILITIES CO2E PRODUCTION    0.00000      LB/HR
    TOTAL CO2E PRODUCTION        0.00000      LB/HR

                          ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE              F                        392.000
   PRESSURE DROP                      PSI                        3.00000
   MAXIMUM NO. ITERATIONS                                       30
   CONVERGENCE TOLERANCE                                        0.000100000



                           ***  RESULTS  ***
   OUTLET TEMPERATURE    F                                   392.00
   OUTLET PRESSURE       PSIA                                11.696
   HEAT DUTY             BTU/HR                             0.11641E+08
   OUTLET VAPOR FRACTION                                     1.0000


   V-L PHASE EQUILIBRIUM :

      COMP             F(I)          X(I)          Y(I)          K(I)
      CH4            0.12125       0.93563E-03   0.12125
0.11370E+06
      NH3            0.12026       0.22180       0.12026       475.71
      CO2            0.38847E-07   0.19251E-08   0.38847E-07   17704.
      HCN            0.10913E-08   0.60892E-08   0.10913E-08   157.23
      CO             0.14821E-05   0.13906E-06   0.14821E-05   9350.7
      H2             0.76190E-07   0.88131E-09   0.76190E-07   75848.
      O2             0.15745       0.12970E-02   0.15745
0.10650E+06
      N2             0.58590       0.36636E-02   0.58590
0.14031E+06
      H2O            0.15146E-01   0.77230       0.15146E-01   17.206
      H3O+            0.0000       0.12869E-07    0.0000       0.0000
      CN-             0.0000       0.25778E-10    0.0000       0.0000
      OH-             0.0000       0.12843E-07    0.0000       0.0000

 BLOCK:  E-101    MODEL: HEATER
 ------------------------------
   INLET STREAM:          8
   OUTLET STREAM:         9
```

```
PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
HENRY-COMPS ID:        GLOBAL
CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT         RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(LBMOL/HR)             5494.49         5494.49       -0.165529E-15
    MASS(LB/HR   )             125317.         125317.         0.00000
    ENTHALPY(BTU/HR  )      -0.264347E+08   -0.949168E+08    0.721497

                    ***  CO2 EQUIVALENT SUMMARY ***
 FEED STREAMS CO2E              5413.75      LB/HR
 PRODUCT STREAMS CO2E           5413.75      LB/HR
 NET STREAMS CO2E PRODUCTION    0.00000      LB/HR
 UTILITIES CO2E PRODUCTION      0.00000      LB/HR
 TOTAL CO2E PRODUCTION          0.00000      LB/HR

                        ***  INPUT DATA  ***
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE              F                       600.800
PRESSURE DROP                      PSI                       3.00000
MAXIMUM NO. ITERATIONS                                      30
CONVERGENCE TOLERANCE                                        0.000100000



                         ***  RESULTS  ***
OUTLET TEMPERATURE    F                                  600.80
OUTLET PRESSURE       PSIA                               26.392
HEAT DUTY             BTU/HR                            -0.68482E+08
OUTLET VAPOR FRACTION                                    1.0000


V-L PHASE EQUILIBRIUM :

   COMP              F(I)           X(I)           Y(I)           K(I)
   CH4             0.20319E-02    0.60573E-05    0.20319E-02     65542.
   NH3             0.19198E-01    0.15855E-02    0.19198E-01     2365.9
   CO2             0.38712E-02    0.30925E-04    0.38712E-02     24459.
   HCN             0.63993E-01    0.52499E-01    0.63993E-01     238.17
   CO              0.37638E-01    0.74475E-03    0.37638E-01     9874.3
   H2              0.11291        0.80833E-03    0.11291         27292.
   O2              0.18302E-01    0.61356E-04    0.18302E-01     58282.
   N2              0.53134        0.17439E-02    0.53134         59531.
   H2O             0.21071        0.94252        0.21071         43.682
   H3O+             0.0000        0.13771E-05     0.0000         0.0000
   CN-              0.0000        0.13761E-05     0.0000         0.0000
   OH-              0.0000        0.10037E-08     0.0000         0.0000
BLOCK:  E-102    MODEL: HEATER
------------------------------
  INLET STREAM:          10
  OUTLET STREAM:         11
  PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
  HENRY-COMPS ID:        GLOBAL
  CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT         RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(LBMOL/HR)             5494.49         5494.49         0.00000
    MASS(LB/HR   )             125317.         125317.       -0.232242E-15
```

```
    ENTHALPY(BTU/HR  )      -0.106558E+09   -0.113344E+09    0.598719E-01

                   ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E                5413.75      LB/HR
   PRODUCT STREAMS CO2E             5413.75      LB/HR
   NET STREAMS CO2E PRODUCTION      0.00000      LB/HR
   UTILITIES CO2E PRODUCTION        0.00000      LB/HR
   TOTAL CO2E PRODUCTION            0.00000      LB/HR

                       ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE                  F                       158.000
  SPECIFIED PRESSURE                     PSIA                     14.6959
  MAXIMUM NO. ITERATIONS                                          30
  CONVERGENCE TOLERANCE                                            0.000100000


                        ***  RESULTS  ***
  OUTLET TEMPERATURE    F                                      158.00
  OUTLET PRESSURE       PSIA                                   14.696
  HEAT DUTY             BTU/HR                               -0.67861E+07
  OUTLET VAPOR FRACTION                                          1.0000


  V-L PHASE EQUILIBRIUM :

     COMP              F(I)           X(I)           Y(I)           K(I)
     CH4             0.20319E-02    0.45212E-07    0.20319E-02     65617.
     NH3             0.19198E-01    0.21806E-02    0.19198E-01     12.854
     CO2             0.38712E-02    0.14715E-05    0.38712E-02     3841.1
     HCN             0.63993E-01    0.38601E-02    0.63993E-01     24.205
     CO              0.37638E-01    0.43027E-04    0.37638E-01     1277.2
     H2              0.11291        0.22051E-05    0.11291         74761.
     O2              0.18302E-01    0.40735E-06    0.18302E-01     65599.
     N2              0.53134        0.67383E-05    0.53134
0.11513E+06
     H2O             0.21071        0.99390        0.21071         0.30954
     H3O+             0.0000        0.57423E-06     0.0000         0.0000
     CN-              0.0000        0.57415E-06     0.0000         0.0000
     OH-              0.0000        0.80810E-10     0.0000         0.0000

 BLOCK:  E-103    MODEL: SEP
 ---------------------------
  INLET STREAM:          22
  OUTLET STREAMS:        NA2CO3      22-23
  PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
  HENRY-COMPS ID:        GLOBAL
  CHEMISTRY ID:          GLOBAL   - TRUE SPECIES


    ***********************************************************************
    *                                                                     *
    *     ERRORS IN BLOCK CALCULATIONS                                    *
    *                                                                     *
    *     SFLASH CONVERGENCE ERROR                                        *
    *                                                                     *
    ***********************************************************************


                   ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
```

```
    MOLE(LBMOL/HR)             1600.34          1600.34          0.142078E-15
    MASS(LB/HR   )             33677.4          33677.4          0.324073E-14
    ENTHALPY(BTU/HR  )       -0.122211E+09    -0.120241E+09    -0.161150E-01

                   ***  CO2 EQUIVALENT SUMMARY ***
 FEED STREAMS CO2E            0.203252E-01  LB/HR
 PRODUCT STREAMS CO2E         0.203252E-01  LB/HR
 NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
 UTILITIES CO2E PRODUCTION     0.00000      LB/HR
 TOTAL CO2E PRODUCTION         0.00000      LB/HR


                        ***  INPUT DATA  ***

 FLASH SPECS FOR STREAM NA2CO3
 TWO    PHASE  TP  FLASH
 PRESSURE DROP         PSI                                      0.0
 MAXIMUM NO. ITERATIONS                                        30
 CONVERGENCE TOLERANCE                                          0.000100000

 FLASH SPECS FOR STREAM 22-23
 TWO    PHASE  TP  FLASH
 PRESSURE DROP         PSI                                      0.0
 MAXIMUM NO. ITERATIONS                                        30
 CONVERGENCE TOLERANCE                                          0.000100000

 FRACTION OF FEED
   SUBSTREAM= MIXED
     STREAM= NA2CO3    CPT= CH4        FRACTION=              0.0
                            NH3                               0.0
                            CO2                               0.0
                            HCN                               0.0
                            CO                                0.0
                            H2                                0.0
                            O2                                0.0
                            N2                                0.0
                            H2O                               0.0
                            NAOH                              0.0
                            H3O+                              0.0
                            CN-                               0.0
                            OH-                               0.0
                            NACN(S)                           0.0
                            NAOH:(S)                          0.0
                            NAOH(S)                           0.0
                            CO3--                             0.80000
                            HCO3-                             0.80000
                            SODIU-01                          0.0
                            SODIU-02                          0.0

 MOLE-FLOW (LBMOL/HR)
   SUBSTREAM= MIXED
     STREAM= NA2CO3    CPT= NA+        FLOW=                  7.97639


                         ***  RESULTS  ***

 HEAT DUTY             BTU/HR                                   0.18173E+35

COMPONENT = CH4
  STREAM     SUBSTREAM    SPLIT FRACTION
  22-23      MIXED                 1.00000

COMPONENT = NH3
  STREAM     SUBSTREAM    SPLIT FRACTION
```

```
    22-23       MIXED                     1.00000

  COMPONENT = CO2
    STREAM      SUBSTREAM    SPLIT FRACTION
    22-23       MIXED                     1.00000

  COMPONENT = HCN
    STREAM      SUBSTREAM    SPLIT FRACTION
    22-23       MIXED                     1.00000

  COMPONENT = CO
    STREAM      SUBSTREAM    SPLIT FRACTION
    22-23       MIXED                     1.00000

  COMPONENT = H2
    STREAM      SUBSTREAM    SPLIT FRACTION
    22-23       MIXED                     1.00000

  COMPONENT = O2
    STREAM      SUBSTREAM    SPLIT FRACTION
    22-23       MIXED                     1.00000

  COMPONENT = N2
    STREAM      SUBSTREAM    SPLIT FRACTION
    22-23       MIXED                     1.00000

  COMPONENT = H2O
    STREAM      SUBSTREAM    SPLIT FRACTION
    22-23       MIXED                     1.00000

  COMPONENT = H3O+
    STREAM      SUBSTREAM    SPLIT FRACTION
    22-23       MIXED                     1.00000

  COMPONENT = NA+
    STREAM      SUBSTREAM    SPLIT FRACTION
    NA2CO3      MIXED                     0.021680
    22-23       MIXED                     0.97832

  COMPONENT = CN-
    STREAM      SUBSTREAM    SPLIT FRACTION
    22-23       MIXED                     1.00000

  COMPONENT = OH-
    STREAM      SUBSTREAM    SPLIT FRACTION
    22-23       MIXED                     1.00000

  COMPONENT = CO3--
    STREAM      SUBSTREAM    SPLIT FRACTION
    NA2CO3      MIXED                     0.80000
    22-23       MIXED                     0.20000

  COMPONENT = HCO3-
    STREAM      SUBSTREAM    SPLIT FRACTION
    NA2CO3      MIXED                     0.80000
    22-23       MIXED                     0.20000

 BLOCK:  E-103HX  MODEL: HEATER
 ------------------------------
   INLET STREAM:           22-23
   OUTLET STREAM:          23
   PROPERTY OPTION SET:    ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:         GLOBAL
   CHEMISTRY ID:           GLOBAL   - TRUE SPECIES
```

```
                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
  TOTAL BALANCE
     MOLE(LBMOL/HR)            1588.38         1588.38        0.143148E-15
     MASS(LB/HR   )            33254.7         33254.7         0.00000
     ENTHALPY(BTU/HR  )      -0.120241E+09   -0.120107E+09   -0.111635E-02

                    ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E           0.203252E-01  LB/HR
  PRODUCT STREAMS CO2E        0.203252E-01  LB/HR
  NET STREAMS CO2E PRODUCTION  0.00000      LB/HR
  UTILITIES CO2E PRODUCTION    0.00000      LB/HR
  TOTAL CO2E PRODUCTION        0.00000      LB/HR

                        ***  INPUT DATA  ***
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE CHANGE        F                             9.00000
 SPECIFIED PRESSURE                  PSIA                         14.6959
 MAXIMUM NO. ITERATIONS                                           30
 CONVERGENCE TOLERANCE                                             0.000100000



                         ***  RESULTS  ***
 OUTLET TEMPERATURE    F                                       196.16
 OUTLET PRESSURE       PSIA                                    14.696
 HEAT DUTY             BTU/HR                                 0.13423E+06
 OUTLET VAPOR FRACTION                                        0.31836E-06



 V-L PHASE EQUILIBRIUM :

    COMP              F(I)           X(I)           Y(I)           K(I)
    CH4             0.84727E-08    0.78666E-08    0.19039E-02
0.24203E+06
    NH3             0.15960E-03    0.15959E-03    0.20080E-01     125.82
    CO2             0.21354E-06    0.21242E-06    0.35318E-02     16626.
    HCN             0.25802E-05    0.28865E-05    0.37258E-03     129.08
    CO              0.63748E-05    0.63619E-05    0.40718E-01     6400.3
    H2              0.44581E-06    0.41290E-06    0.10340
0.25042E+06
    O2              0.77505E-07    0.72051E-07    0.17132E-01
0.23777E+06
    N2              0.13306E-05    0.11811E-05    0.46969
0.39768E+06
    H2O             0.54723        0.54723        0.34318        0.62711
    H3O+            0.51181E-14    0.67284E-14     0.0000         0.0000
    NA+             0.22661        0.22661         0.0000         0.0000
    CN-             0.22136        0.22136         0.0000         0.0000
    OH-             0.39978E-02    0.39981E-02     0.0000         0.0000
    CO3--           0.62760E-03    0.62760E-03     0.0000         0.0000
    HCO3-           0.11926E-06    0.11926E-06     0.0000         0.0000

 BLOCK:  E-105    MODEL: SEP
 ---------------------------
   INLET STREAM:          31
   OUTLET STREAMS:        33          32
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                    ***  MASS AND ENERGY BALANCE  ***
```

```
                                  IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           770.984         770.984         0.00000
       MASS(LB/HR   )           22429.8         22429.8         0.00000
       ENTHALPY(BTU/HR  )     -0.112929E+08   -0.118755E+08    0.490545E-01

                       ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E               0.00000      LB/HR
    PRODUCT STREAMS CO2E            0.00000      LB/HR
    NET STREAMS CO2E PRODUCTION     0.00000      LB/HR
    UTILITIES CO2E PRODUCTION       0.00000      LB/HR
    TOTAL CO2E PRODUCTION           0.00000      LB/HR


                           ***  INPUT DATA  ***

   FLASH SPECS FOR STREAM 33
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE F                                     122.000
   PRESSURE DROP         PSI                                     3.00000
   MAXIMUM NO. ITERATIONS                                       30
   CONVERGENCE TOLERANCE                                         0.000100000

   FLASH SPECS FOR STREAM 32
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE F                                     122.000
   PRESSURE DROP         PSI                                     3.00000
   MAXIMUM NO. ITERATIONS                                       30
   CONVERGENCE TOLERANCE                                         0.000100000

   FRACTION OF FEED
     SUBSTREAM= MIXED
       STREAM= 32         CPT= O2        FRACTION=             1.00000
                               N2                              1.00000

   MASS FLOW (LB/HR   )
     SUBSTREAM= MIXED
       STREAM= 32         CPT= H2O       FLOW=             1,543.24


                            ***  RESULTS  ***

   HEAT DUTY              BTU/HR                                -0.58254E+06

  COMPONENT = O2
    STREAM     SUBSTREAM    SPLIT FRACTION
    32         MIXED                 1.00000

  COMPONENT = N2
    STREAM     SUBSTREAM    SPLIT FRACTION
    32         MIXED                 1.00000

  COMPONENT = H2O
    STREAM     SUBSTREAM    SPLIT FRACTION
    33         MIXED                 0.23414
    32         MIXED                 0.76586

 BLOCK:  E-106    MODEL: HEATER
 ------------------------------
   INLET STREAM:           34
   OUTLET STREAM:          35
   PROPERTY OPTION SET:    ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:         GLOBAL
   CHEMISTRY ID:           GLOBAL   - TRUE SPECIES
```

```
                  ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)          744.796         744.796         0.00000
      MASS(LB/HR   )          21958.0         21958.0         0.00000
      ENTHALPY(BTU/HR  )    -0.806686E+07   -0.770602E+07   -0.447315E-01

                  ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E              0.00000      LB/HR
   PRODUCT STREAMS CO2E           0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION    0.00000      LB/HR
   UTILITIES CO2E PRODUCTION      0.00000      LB/HR
   TOTAL CO2E PRODUCTION          0.00000      LB/HR

                      ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE               F                        302.000
  PRESSURE DROP                       PSI                        3.00000
  MAXIMUM NO. ITERATIONS                                       30
  CONVERGENCE TOLERANCE                                          0.000100000



                       ***  RESULTS  ***
  OUTLET TEMPERATURE    F                                    302.00
  OUTLET PRESSURE       PSIA                                 20.696
  HEAT DUTY             BTU/HR                              0.36084E+06
  OUTLET VAPOR FRACTION                                      1.0000



  V-L PHASE EQUILIBRIUM :

     COMP              F(I)          X(I)          Y(I)          K(I)
     O2              0.65701       0.34301E-03   0.65701       54264.
     N2              0.22797       0.80955E-04   0.22797       79778.
     H2O             0.11501       0.99958       0.11501       3.2597
     H3O+             0.0000       0.27520E-07    0.0000       0.0000
     OH-              0.0000       0.27520E-07    0.0000       0.0000

BLOCK:  E100B    MODEL: HEATER
------------------------------
  INLET STREAM:          9
  OUTLET STREAM:         10
  PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
  HENRY-COMPS ID:        GLOBAL
  CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                  ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)          5494.49         5494.49         0.00000
      MASS(LB/HR   )          125317.         125317.         0.00000
      ENTHALPY(BTU/HR  )    -0.949168E+08   -0.106558E+09    0.109248

                  ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E              5413.75      LB/HR
   PRODUCT STREAMS CO2E           5413.75      LB/HR
   NET STREAMS CO2E PRODUCTION    0.00000      LB/HR
   UTILITIES CO2E PRODUCTION      0.00000      LB/HR
   TOTAL CO2E PRODUCTION          0.00000      LB/HR

                      ***  INPUT DATA  ***
```

```
  TWO    PHASE  PQ  FLASH
  PRESSURE DROP                        PSI                        3.00000
  SPECIFIED HEAT DUTY                  BTU/HR                    -0.116412+08
  MAXIMUM NO. ITERATIONS                                         30
  CONVERGENCE TOLERANCE                                           0.000100000


                        ***  RESULTS  ***
  OUTLET TEMPERATURE    F                                     324.05
  OUTLET PRESSURE       PSIA                                  23.392
  OUTLET VAPOR FRACTION                                       1.0000


  V-L PHASE EQUILIBRIUM :

     COMP             F(I)          X(I)          Y(I)          K(I)
     CH4            0.20319E-02   0.71479E-06   0.20319E-02   3537.1
     NH3            0.19198E-01   0.50068E-02   0.19198E-01   31.693
     CO2            0.38712E-02   0.11610E-04   0.38712E-02   817.95
     HCN            0.63993E-01   0.22182E-01   0.63993E-01   9.4567
     CO             0.37638E-01   0.22052E-03   0.37638E-01   637.12
     H2             0.11291       0.51207E-04   0.11291       1894.6
     O2             0.18302E-01   0.67644E-05   0.18302E-01   3217.6
     N2             0.53134       0.13722E-03   0.53134       3775.2
     H2O            0.21071       0.97238       0.21071       4.0242
     H3O+            0.0000       0.26178E-05    0.0000       0.0000
     CN-             0.0000       0.26175E-05    0.0000       0.0000
     OH-             0.0000       0.25046E-09    0.0000       0.0000

BLOCK:  MIX1     MODEL: MIXER
-----------------------------
  INLET STREAMS:         20          1-5
  OUTLET STREAM:         6
  PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
  HENRY-COMPS ID:        GLOBAL
  CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                   ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            4872.87        4872.86        0.104014E-05
      MASS(LB/HR   )            125317.        125317.        0.728965E-06
      ENTHALPY(BTU/HR  )      -0.381674E+08  -0.381668E+08   -0.137741E-04

                   ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E              236967.      LB/HR
   PRODUCT STREAMS CO2E           236967.      LB/HR
   NET STREAMS CO2E PRODUCTION    0.00000      LB/HR
   UTILITIES CO2E PRODUCTION      0.00000      LB/HR
   TOTAL CO2E PRODUCTION          0.00000      LB/HR

                       ***  INPUT DATA  ***
  TWO    PHASE      FLASH
  MAXIMUM NO. ITERATIONS                                    30
  CONVERGENCE TOLERANCE                                      0.000100000
  OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

BLOCK:  MIX2     MODEL: MIXER
-----------------------------
  INLET STREAMS:         23          29
  OUTLET STREAM:         24
  PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
```

```
  HENRY-COMPS ID:        GLOBAL
  CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

    ***********************************************************************
    *                                                                     *
    *     AT LEAST ONE OF THE INLET OR OUTLET STREAMS                     *
    *     IS NOT IN CHARGE BALANCE                                        *
    *                                                                     *
    ***********************************************************************

                     ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            5040.39         5040.39       -0.107699E-06
      MASS(LB/HR   )            101735.         101735.        0.143038E-15
      ENTHALPY(BTU/HR  )      -0.450904E+09   -0.450903E+09   -0.334492E-06

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.203255E-01  LB/HR
   PRODUCT STREAMS CO2E         0.203255E-01  LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                         ***  INPUT DATA  ***
  TWO    PHASE      FLASH
  MAXIMUM NO. ITERATIONS                                    30
  CONVERGENCE TOLERANCE                                      0.000100000
  OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

BLOCK:  P-101    MODEL: PUMP
----------------------------
  INLET STREAM:          25
  OUTLET STREAM:         28
  PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
  HENRY-COMPS ID:        GLOBAL
  CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

    ***********************************************************************
    *                                                                     *
    *     AT LEAST ONE OF THE INLET OR OUTLET STREAMS                     *
    *     IS NOT IN CHARGE BALANCE                                        *
    *                                                                     *
    ***********************************************************************

                     ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            3851.94         3851.94        0.745337E-06
      MASS(LB/HR   )            86598.9         86598.9         0.00000
      ENTHALPY(BTU/HR  )      -0.348961E+09   -0.348955E+09   -0.150195E-04

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.257860E-06  LB/HR
   PRODUCT STREAMS CO2E         0.258186E-06  LB/HR
   NET STREAMS CO2E PRODUCTION  0.326311E-09  LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION        0.326311E-09  LB/HR

                         ***  INPUT DATA  ***
```

```
    OUTLET PRESSURE  PSIA                                            14.5038
    DRIVER EFFICIENCY                                                 1.00000

    FLASH SPECIFICATIONS:
    LIQUID PHASE CALCULATION
    NO FLASH PERFORMED
    MAXIMUM NUMBER OF ITERATIONS                                      30
    TOLERANCE                                                         0.000100000

                           ***  RESULTS  ***
    VOLUMETRIC FLOW RATE  CUFT/HR                                  1,221.04
    PRESSURE CHANGE  PSI                                             13.6037
    NPSH AVAILABLE   FT-LBF/LB                                        0.0
    FLUID POWER  HP                                                   1.20805
    BRAKE POWER  HP                                                   2.05504
    ELECTRICITY  KW                                                   1.53244
    PUMP EFFICIENCY USED                                              0.58785
    NET WORK REQUIRED  HP                                             2.05504
    HEAD DEVELOPED FT-LBF/LB                                         34.3557

 BLOCK:  P-102    MODEL: COMPR
 -----------------------------
   INLET STREAM:          32
   OUTLET STREAM:         34
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            744.796         744.796         0.00000
       MASS(LB/HR   )            21958.0         21958.0         0.00000
       ENTHALPY(BTU/HR  )      -0.867652E+07   -0.806686E+07   -0.702650E-01

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E              0.00000      LB/HR
    PRODUCT STREAMS CO2E           0.00000      LB/HR
    NET STREAMS CO2E PRODUCTION    0.00000      LB/HR
    UTILITIES CO2E PRODUCTION      0.00000      LB/HR
    TOTAL CO2E PRODUCTION          0.00000      LB/HR

                           ***  INPUT DATA  ***

   ISENTROPIC CENTRIFUGAL COMPRESSOR
    PRESSURE CHANGE  PSI                                               9.00000
    ISENTROPIC EFFICIENCY                                              0.72000
    MECHANICAL EFFICIENCY                                              1.00000

                           ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  HP                            239.604
    BRAKE      HORSEPOWER REQUIREMENT  HP                            239.604
    NET WORK REQUIRED                  HP                            239.604
    POWER LOSSES                       HP                              0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  HP                            172.515
    CALCULATED OUTLET PRES  PSIA                                      23.6959
    CALCULATED OUTLET TEMP  F                                        235.713
    ISENTROPIC TEMPERATURE  F                                        204.128
    EFFICIENCY (POLYTR/ISENTR) USED                                    0.72000
    OUTLET VAPOR FRACTION                                              1.00000
    HEAD DEVELOPED,       FT-LBF/LB                               15,556.0
    MECHANICAL EFFICIENCY USED                                         1.00000
    INLET HEAT CAPACITY RATIO                                          1.38661
```

```
    INLET VOLUMETRIC FLOW RATE , CUFT/HR               316,008.
    OUTLET VOLUMETRIC FLOW RATE, CUFT/HR               234,355.
    INLET  COMPRESSIBILITY FACTOR                            0.99891
    OUTLET COMPRESSIBILITY FACTOR                            0.99915
    AV. ISENT. VOL. EXPONENT                                 1.38229
    AV. ISENT. TEMP EXPONENT                                 1.38210
    AV. ACTUAL VOL. EXPONENT                                 1.59814
    AV. ACTUAL TEMP EXPONENT                                 1.59684

 BLOCK:  R-100    MODEL: RSTOIC
 ------------------------------
   INLET STREAM:          7
   OUTLET STREAM:         8
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                      ***  MASS AND ENERGY BALANCE  ***
                                IN          OUT      GENERATION   RELATIVE
DIFF.
   TOTAL BALANCE
   MOLE(LBMOL/HR)         4872.86      5494.49      621.624      0.00000
   MASS(LB/HR   )         125317.      125317.                  -0.116121E-
15
   ENTHALPY(BTU/HR  )   -0.265256E+08 -0.264347E+08             -0.342940E-
02

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E              236967.      LB/HR
    PRODUCT STREAMS CO2E           5413.75      LB/HR
    NET STREAMS CO2E PRODUCTION  -231553.      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION        -231553.      LB/HR

                          ***  INPUT DATA  ***
   STOICHIOMETRY MATRIX:

    REACTION #   1:
     SUBSTREAM MIXED   :
     CH4       -1.00    NH3       -1.00    HCN        1.00    O2        -1.50
     H2O        3.00
     SUBSTREAM CISOLID :
     NO PARTICIPATING COMPONENTS

    REACTION #   2:
     SUBSTREAM MIXED   :
     CH4       -1.00    CO         1.00    H2         3.00    H2O       -1.00
     SUBSTREAM CISOLID :
     NO PARTICIPATING COMPONENTS

    REACTION #   3:
     SUBSTREAM MIXED   :
     CH4       -1.00    CO2        1.00    O2        -2.00    H2O        2.00
     SUBSTREAM CISOLID :
     NO PARTICIPATING COMPONENTS

    REACTION #   4:
     SUBSTREAM MIXED   :
     NH3       -4.00    O2        -3.00    N2         2.00    H2O        6.00
     SUBSTREAM CISOLID :
     NO PARTICIPATING COMPONENTS


   REACTION CONVERSION SPECS: NUMBER=    4
```

```
    REACTION #    1:
    SUBSTREAM:MIXED    KEY COMP:NH3      CONV FRAC: 0.6000
    REACTION #    2:
    SUBSTREAM:MIXED    KEY COMP:CH4      CONV FRAC: 0.3500
    REACTION #    3:
    SUBSTREAM:MIXED    KEY COMP:CH4      CONV FRAC: 0.3600E-01
    REACTION #    4:
    SUBSTREAM:MIXED    KEY COMP:NH3      CONV FRAC: 0.2200


  ONE    PHASE  TP  FLASH   SPECIFIED PHASE IS  VAPOR
  SPECIFIED TEMPERATURE F                                   2,058.80
  SPECIFIED PRESSURE    PSIA                                   29.3919
  MAXIMUM NO. ITERATIONS                                       30
  CONVERGENCE TOLERANCE                                         0.000100000
  SIMULTANEOUS REACTIONS
  GENERATE COMBUSTION REACTIONS FOR FEED SPECIES           NO

                        ***  RESULTS  ***
  OUTLET TEMPERATURE    F                                       2058.8
  OUTLET PRESSURE       PSIA                                    29.392
  HEAT DUTY             BTU/HR                                  90967.


  HEAT OF REACTIONS:

    REACTION          REFERENCE          HEAT OF
    NUMBER            COMPONENT          REACTION
                                          BTU/LBMOL
     1                   CH4              -0.20424E+06
     2                   CH4                88723.
     3                   CH4              -0.34524E+06
     4                   NH3              -0.13643E+06

  REACTION EXTENTS:

     REACTION          REACTION
     NUMBER            EXTENT
                       LBMOL/HR
     1                  351.61
     2                  206.79
     3                  21.270
     4                  32.231

BLOCK:  SEP-100  MODEL: CRYSTALLIZER
------------------------------------
  INLET STREAM:          24
  OUTLET STREAMS:        25          26
  PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
  HENRY-COMPS ID:        GLOBAL
  CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

    ***********************************************************************
    *                                                                     *
    *     AT LEAST ONE OF THE INLET OR OUTLET STREAMS                     *
    *     IS NOT IN CHARGE BALANCE                                        *
    *                                                                     *
    ***********************************************************************
```

```
                    ***  MASS AND ENERGY BALANCE  ***
                            IN           OUT       GENERATION   RELATIVE
DIFF.
   TOTAL BALANCE
   MOLE(LBMOL/HR)        5040.39       4692.12       0.00000      0.690959E-
01
   MASS(LB/HR   )        101735.       101735.                   -0.143038E-
15
   ENTHALPY(BTU/HR  )   -0.450903E+09 -0.435923E+09              -0.332231E-
01

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E           0.203255E-01  LB/HR
    PRODUCT STREAMS CO2E        0.203255E-01  LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000     LB/HR
    UTILITIES CO2E PRODUCTION     0.00000     LB/HR
    TOTAL CO2E PRODUCTION         0.00000     LB/HR

                        ***  INPUT DATA  ***

    CRYSTALLIZER TEMPERATURE   F                                 140.00
    CRYSTAL PRODUCT FLOW RATE  LB/HR                             16976.
    FRAC OF FLOW RECYCLED                                        0.0000



                         ***  RESULTS  ***
    HEATER DUTY                BTU/HR                           0.14980E+08
    CRYSTALLIZER PRESSURE      PSIA                             0.90011
    CRYSTAL PRODUCT FLOW RATE  LB/HR                             16976.
    MAGMA DENSITY              LB/CUFT                           12.266
    VENT FLOW RATE             LB/HR                             15136.
    RECYCLE FLOW RATE          LB/HR                             0.0000

 BLOCK:  SEP-101  MODEL: CFUGE
 -----------------------------
   INLET STREAM:          28
   OUTLET STREAMS:        29         30
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES


     ***********************************************************************
     *                                                                     *
     *     AT LEAST ONE OF THE INLET OR OUTLET STREAMS                     *
     *     IS NOT IN CHARGE BALANCE                                        *
     *                                                                     *
     ***********************************************************************


                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT         RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           3851.94         3851.91        0.754527E-05
       MASS(LB/HR   )           86598.9         86598.4        0.549456E-05
       ENTHALPY(BTU/HR  )     -0.348955E+09   -0.348950E+09   -0.162349E-04

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E           0.258186E-06  LB/HR
    PRODUCT STREAMS CO2E        0.257958E-06  LB/HR
    NET STREAMS CO2E PRODUCTION -0.228268E-09  LB/HR
    UTILITIES CO2E PRODUCTION     0.00000     LB/HR
    TOTAL CO2E PRODUCTION       -0.228268E-09  LB/HR
```

```
                          ***  INPUT DATA  ***
   CALCULATION METHOD                                              SOLIDS SEPARATOR
   CLASSIFICATION CHARACTERISTIC                                   SETTLING VELOCITY
   FLUID RECOVERY TO FLUID OUTLET                                    0.98500
   SOLIDS RECOVERY TO SOLIDS OUTLET                                  1.00000
   SEPARATION SHARPNESS                                              0.0
   FINES OFFSET                                                      0.0

   TWO    PHASE  PQ  FLASH
   PRESSURE DROP          PSI                                          0.0
   SPECIFIED HEAT DUTY   BTU/HR                                        0.0
   MAXIMUM NO. ITERATIONS                                             30
   CONVERGENCE TOLERANCE                                               0.000100000

                           ***  RESULTS  ***
   FLUID FRACTION TO FLUID OUTLET                                    0.98500
   SOLIDS FRACTION TO SOLID OUTLET                                   1.00000
   SOLIDS LOAD OF FLUID                                              0.818930-06
   FLUID LOAD OF SOLIDS                                              0.061073

 BLOCK:  SEP-102  MODEL: SEP
 ---------------------------
   INLET STREAM:           30
   OUTLET STREAMS:         VAP          36
   PROPERTY OPTION SET:    ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:         GLOBAL
   CHEMISTRY ID:           GLOBAL   - TRUE SPECIES


     ***********************************************************************
     *                                                                     *
     *     AT LEAST ONE OF THE INLET OR OUTLET STREAMS                     *
     *     IS NOT IN CHARGE BALANCE                                        *
     *                                                                     *
     ***********************************************************************


                      ***  MASS AND ENERGY BALANCE  ***
                                       IN              OUT          RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)             399.904          394.736          0.129232E-01
       MASS(LB/HR    )            18118.3          18118.3           0.00000
       ENTHALPY(BTU/HR  )       -0.181532E+08    -0.181103E+08    -0.236354E-02

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.379366E-08  LB/HR
    PRODUCT STREAMS CO2E         0.379366E-08  LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR


                          ***  INPUT DATA  ***

   FLASH SPECS FOR STREAM VAP
   TWO    PHASE  TP  FLASH
   PRESSURE DROP          PSI                                          0.0
   MAXIMUM NO. ITERATIONS                                             30
   CONVERGENCE TOLERANCE                                               0.000100000

   FLASH SPECS FOR STREAM 36
   TWO    PHASE  TP  FLASH
   PRESSURE DROP          PSI                                          0.0
```

```
 MAXIMUM NO. ITERATIONS                                         30
 CONVERGENCE TOLERANCE                                           0.000100000

 MASS FLOW (LB/HR   )
   SUBSTREAM= MIXED
     STREAM= VAP       CPT= H2O       FLOW=            471.789

                              ***  RESULTS  ***

 HEAT DUTY              BTU/HR                                  42906.

COMPONENT = NH3
  STREAM      SUBSTREAM    SPLIT FRACTION
  36          MIXED                 1.00000

COMPONENT = CO2
  STREAM      SUBSTREAM    SPLIT FRACTION
  36          MIXED                 1.00000

COMPONENT = HCN
  STREAM      SUBSTREAM    SPLIT FRACTION
  36          MIXED                 1.00000

COMPONENT = CO
  STREAM      SUBSTREAM    SPLIT FRACTION
  36          MIXED                 1.00000

COMPONENT = N2
  STREAM      SUBSTREAM    SPLIT FRACTION
  36          MIXED                 1.00000

COMPONENT = H2O
  STREAM      SUBSTREAM    SPLIT FRACTION
  VAP         MIXED                 0.89440
  36          MIXED                 0.10560

COMPONENT = NA+
  STREAM      SUBSTREAM    SPLIT FRACTION
  36          MIXED                 1.00000

COMPONENT = CN-
  STREAM      SUBSTREAM    SPLIT FRACTION
  36          MIXED                 1.00000

COMPONENT = OH-
  STREAM      SUBSTREAM    SPLIT FRACTION
  36          MIXED                 1.00000

COMPONENT = NACN(S)
  STREAM      SUBSTREAM    SPLIT FRACTION
  36          CISOLID               1.00000

COMPONENT = CO3--
  STREAM      SUBSTREAM    SPLIT FRACTION
  36          MIXED                 1.00000

COMPONENT = HCO3-
  STREAM      SUBSTREAM    SPLIT FRACTION
  36          MIXED                 1.00000

COMPONENT = SODIU-02
  STREAM      SUBSTREAM    SPLIT FRACTION
  36          MIXED                 1.00000
```

```
 BLOCK:  V-100    MODEL: RADFRAC
 -------------------------------
    INLETS   - 21       STAGE   1
               11       STAGE   2
    OUTLETS  - 12       STAGE   1
               22       STAGE   2
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                     ***  MASS AND ENERGY BALANCE  ***
                             IN           OUT       GENERATION   RELATIVE
DIFF.
   TOTAL BALANCE
   MOLE(LBMOL/HR)         7047.19      7042.20      -4.98525      0.186398E-
11
   MASS(LB/HR   )         154748.      154748.                    0.342423E-
11
   ENTHALPY(BTU/HR  )   -0.284020E+09 -0.284020E+09              -0.950917E-
06

                     ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E              5413.75      LB/HR
    PRODUCT STREAMS CO2E           5194.35      LB/HR
    NET STREAMS CO2E PRODUCTION   -219.400      LB/HR
    UTILITIES CO2E PRODUCTION      0.00000      LB/HR
    TOTAL CO2E PRODUCTION         -219.400      LB/HR


                        **********************
                        ****  INPUT DATA  ****
                        **********************

   ****   INPUT PARAMETERS   ****

    NUMBER OF STAGES                                              2
    ALGORITHM OPTION                                           STANDARD
    INITIALIZATION OPTION                                      STANDARD
    HYDRAULIC PARAMETER CALCULATIONS                           NO
    INSIDE LOOP CONVERGENCE METHOD                             NEWTON
    DESIGN SPECIFICATION METHOD                                NESTED
    MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS                       25
    MAXIMUM NO. OF INSIDE LOOP ITERATIONS                        10
    MAXIMUM NUMBER OF FLASH ITERATIONS                           30
    FLASH TOLERANCE                                               0.000100000
    OUTSIDE LOOP CONVERGENCE TOLERANCE                            0.000100000

   ****   COL-SPECS   ****

    MOLAR VAPOR DIST / TOTAL DIST                                 1.00000
    CONDENSER DUTY (W/O SUBCOOL)   BTU/HR                         0.0
    REBOILER DUTY                  BTU/HR                         0.0

   **** REAC-STAGES SPECIFICATIONS ****

    STAGE  TO  STAGE            REACTIONS/CHEMISTRY ID
      1          2                     NACN


       *****  REACTION PARAGRAPH NACN    *****
```

**** REACTION PARAMETERS ****

RXN NO.	TYPE	PHASE	CONC. BASIS	TEMP APP TO EQUIL F	CONVERSION
1	EQUILIBRIUM	LIQUID	MOLE-GAMMA	0.0000	
2	EQUILIBRIUM	LIQUID	MOLE-GAMMA	0.0000	
3	CONVERSION				SIMULTANEOUS
4	EQUILIBRIUM	LIQUID	MOLE-GAMMA	0.0000	

** STOICHIOMETRIC COEFFICIENTS **

RXN NO.	CH4	NH3	CO2	HCN	CO
1	0.000	0.000	0.000	-1.000	0.000
2	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	-1.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000

RXN NO.	H2	O2	N2	H2O	H3O+
1	0.000	0.000	0.000	1.000	0.000
2	0.000	0.000	0.000	-2.000	1.000
3	0.000	0.000	0.000	-2.000	1.000
4	0.000	0.000	0.000	-1.000	1.000

RXN NO.	NA+	CN-	OH-	CO3--	HCO3-
1	0.000	1.000	-1.000	0.000	0.000
2	0.000	0.000	1.000	0.000	0.000
3	0.000	0.000	0.000	0.000	1.000
4	0.000	0.000	0.000	1.000	-1.000

** COEFFICIENTS OF CONVERSION EXPRESSION **

RXN NO.	COMPONENT ID	A	B	C	D
3	CO2	0.12500	0.0000	0.0000	0.0000

**** PROFILES ****

P-SPEC STAGE 1 PRES, PSIA 14.6959

****
**** RESULTS ****
****

*** COMPONENT SPLIT FRACTIONS ***

COMPONENT:	12	22
		OUTLET STREAMS
CH4	1.0000	.12054E-05
NH3	.99760	.24033E-02
CO2	.99998	.20828E-04
HCN	.44376	.55624
CO	.99995	.48963E-04
H2	1.0000	.11414E-05
O2	1.0000	.12242E-05
N2	1.0000	.72395E-06
H2O	.62714	.37286
H3O+	0.0000	1.0000
NA+	0.0000	1.0000
CN-	0.0000	1.0000
OH-	0.0000	1.0000
CO3--	0.0000	1.0000

```
 HCO3-        0.0000       1.0000


***    SUMMARY OF KEY RESULTS    ***

 TOP STAGE TEMPERATURE          F                        211.476
 BOTTOM STAGE TEMPERATURE       F                        187.134
 TOP STAGE LIQUID FLOW          LBMOL/HR               1,657.44
 BOTTOM STAGE LIQUID FLOW       LBMOL/HR               1,600.34
 TOP STAGE VAPOR FLOW           LBMOL/HR               5,441.86
 BOILUP VAPOR FLOW              LBMOL/HR               5,548.93
 CONDENSER DUTY (W/O SUBCOOL)   BTU/HR                     0.0
 REBOILER DUTY                  BTU/HR                     0.0

****   MAXIMUM FINAL RELATIVE ERRORS   ****

 BUBBLE POINT                     0.59054E-06  STAGE=  1
 COMPONENT MASS BALANCE           0.92464E-06  STAGE=  1 COMP=H3O+
 ENERGY BALANCE                   0.36040E-07  STAGE=  2


****    PROFILES   ****

**NOTE** REPORTED VALUES FOR STAGE LIQUID AND VAPOR RATES ARE THE FLOWS
         FROM THE STAGE INCLUDING ANY SIDE PRODUCT.

                                            ENTHALPY
STAGE TEMPERATURE   PRESSURE               BTU/LBMOL           HEAT DUTY
      F             PSIA           LIQUID       VAPOR           BTU/HR

   1   211.48        14.696      -0.10942E+06  -29734.
   2   187.13        14.696       -76365.      -31086.

STAGE      FLOW RATE                     FEED RATE                 PRODUCT RATE
            LBMOL/HR                      LBMOL/HR                   LBMOL/HR
      LIQUID     VAPOR       LIQUID     VAPOR     MIXED       LIQUID     VAPOR
   1  1657.      5442.      1552.7001
5441.8598
   2  1600.      5549.                            5494.4877  1600.3427

    ****  MASS FLOW PROFILES  ****

STAGE      FLOW RATE                     FEED RATE                 PRODUCT RATE
            LB/HR                         LB/HR                      LB/HR
      LIQUID     VAPOR       LIQUID     VAPOR     MIXED       LIQUID     VAPOR
   1 0.3150E+05 0.1211E+06  .29432+05
.12107+06
   2 0.3368E+05 0.1231E+06                        .12532+06  .33677+05

                         ****   MOLE-X-PROFILE     ****
   STAGE     CH4           NH3           CO2           HCN           CO
      1     0.56110E-08   0.10047E-03   0.11178E-06   0.27108E-08   0.34962E-
05
      2     0.84094E-08   0.15841E-03   0.21195E-06   0.13962E-04   0.63272E-
05

                         ****   MOLE-X-PROFILE     ****
   STAGE     H2            O2            N2            H2O           H3O+
      1     0.31178E-06   0.51632E-07   0.91310E-06   0.55733       0.11551E-
16
      2     0.44248E-06   0.76926E-07   0.13207E-05   0.54313       0.38701E-
14

                         ****   MOLE-X-PROFILE     ****
```

STAGE	NA+	CN-	OH-	CO3--	HCO3-
1	0.22198	0.55282E-02	0.21365	0.14036E-02	0.41005E-08
2	0.22990	0.21969	0.39793E-02	0.31145E-02	0.59184E-06

**** MOLE-Y-PROFILE ****

STAGE	CH4	NH3	CO2	HCN	CO
1	0.20516E-02	0.19337E-01	0.29925E-02	0.58846E-06	0.38000E-01
2	0.20120E-02	0.18994E-01	0.33541E-02	0.16518E-02	0.37268E-01

**** MOLE-Y-PROFILE ****

STAGE	H2	O2	N2	H2O	H3O+
1	0.11400	0.18479E-01	0.53648	0.26866	0.0000
2	0.11180	0.18122E-01	0.52613	0.28067	0.0000

**** MOLE-Y-PROFILE ****

STAGE	NA+	CN-	OH-	CO3--	HCO3-
1	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000

**** K-VALUES ****

STAGE	CH4	NH3	CO2	HCN	CO
1	0.36563E+06	192.47	26772.	217.08	10869.
2	0.23925E+06	119.91	15825.	118.31	5890.1

**** K-VALUES ****

STAGE	H2	O2	N2	H2O	H3O+
1	0.36565E+06	0.35790E+06	0.58753E+06	0.48204	0.0000
2	0.25267E+06	0.23558E+06	0.39838E+06	0.51676	0.0000

**** K-VALUES ****

STAGE	NA+	CN-	OH-	CO3--	HCO3-
1	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000

**** RATES OF GENERATION ****
LBMOL/HR

STAGE	CH4	NH3	CO2	HCN	CO	H2
1	0.000	0.000	-2.326	-9.163	0.000	0.000
2	0.000	0.000	-2.659	-342.4	0.000	0.000

**** RATES OF GENERATION ****
LBMOL/HR

STAGE	O2	N2	H2O	H3O+	NA+	CN-
1	0.000	0.000	11.49	0.6564E-08	0.000	9.163
2	0.000	0.000	345.1	0.6174E-11	0.000	342.4

**** RATES OF GENERATION ****
LBMOL/HR

STAGE	OH-	CO3--	HCO3-
1	-13.82	2.326	0.6803E-05
2	-347.7	2.658	0.9404E-03

**** MASS-X-PROFILE ****

STAGE	CH4	NH3	CO2	HCN	CO
1	0.47359E-08	0.90019E-04	0.25881E-06	0.38544E-08	0.51523E-05
2	0.64109E-08	0.12820E-03	0.44325E-06	0.17931E-04	0.84218E-05

**** MASS-X-PROFILE ****

```
   STAGE      H2            O2            N2            H2O           H3O+
      1    0.33066E-07   0.86922E-07   0.13458E-05   0.52825       0.11561E-
16
      2    0.42387E-07   0.11697E-06   0.17581E-05   0.46496       0.34984E-
14

                        ****   MASS-X-PROFILE     ****
   STAGE      NA+           CN-           OH-           CO3--         HCO3-
      1    0.26849       0.75673E-02   0.19117       0.44315E-02   0.13163E-
07
      2    0.25116       0.27163       0.32161E-02   0.88816E-02   0.17161E-
05

                        ****   MASS-Y-PROFILE     ****
   STAGE      CH4           NH3           CO2           HCN           CO
      1    0.14793E-02   0.14802E-01   0.59196E-02   0.71483E-06   0.47842E-
01
      2    0.14545E-02   0.14576E-01   0.66515E-02   0.20116E-02   0.47039E-
01

                        ****   MASS-Y-PROFILE     ****
   STAGE      H2            O2            N2            H2O           H3O+
      1    0.10330E-01   0.26578E-01   0.67550       0.21754        0.0000
      2    0.10156E-01   0.26130E-01   0.66414       0.22784        0.0000

                        ****   MASS-Y-PROFILE     ****
   STAGE      NA+           CN-           OH-           CO3--         HCO3-
      1     0.0000        0.0000        0.0000        0.0000        0.0000
      2     0.0000        0.0000        0.0000        0.0000        0.0000

 BLOCK:  V-101    MODEL: RADFRAC
 -------------------------------
    INLETS    - 12       STAGE   2
                18       STAGE   1
    OUTLETS   - 13       STAGE   1
                14-15    STAGE   2
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                     ***  MASS AND ENERGY BALANCE  ***
                                IN           OUT       GENERATION   RELATIVE
DIFF.
   TOTAL BALANCE
   MOLE(LBMOL/HR)         6367.80       6367.80     -0.826073E-13 -0.142827E-
15
   MASS(LB/HR   )         146460.       146460.                    0.384682E-
10
   ENTHALPY(BTU/HR  )   -0.313249E+09 -0.313249E+09                0.236325E-
06

                     ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            5194.33      LB/HR
    PRODUCT STREAMS CO2E         5194.33      LB/HR
    NET STREAMS CO2E PRODUCTION -0.110565E-05  LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION       -0.110565E-05  LB/HR


                        **********************
                        ****  INPUT DATA  ****
                        **********************
```

```
****   INPUT PARAMETERS   ****

 NUMBER OF STAGES                                                  2
 ALGORITHM OPTION                                               STANDARD
 INITIALIZATION OPTION                                          STANDARD
 HYDRAULIC PARAMETER CALCULATIONS                               NO
 INSIDE LOOP CONVERGENCE METHOD                                 NEWTON
 DESIGN SPECIFICATION METHOD                                    NESTED
 MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS                           25
 MAXIMUM NO. OF INSIDE LOOP ITERATIONS                            10
 MAXIMUM NUMBER OF FLASH ITERATIONS                               30
 FLASH TOLERANCE                                                   0.000100000
 OUTSIDE LOOP CONVERGENCE TOLERANCE                                0.000100000

****   COL-SPECS   ****

 MOLAR VAPOR DIST / TOTAL DIST                                     1.00000
 CONDENSER DUTY (W/O SUBCOOL)    BTU/HR                            0.0
 REBOILER DUTY                   BTU/HR                            0.0

**** REAC-STAGES SPECIFICATIONS ****

 STAGE  TO  STAGE            REACTIONS/CHEMISTRY ID
   1          2                     PHOSFORM


     *****  REACTION PARAGRAPH PHOSFORM*****


       ****  REACTION PARAMETERS  ****

RXN NO. TYPE          PHASE      CONC.    TEMP APP TO EQUIL    CONVERSION
                                 BASIS             F
   1    EQUILIBRIUM  LIQUID     MOLE-GAMMA      0.0000

     **  STOICHIOMETRIC COEFFICIENTS  **

RXN NO.     CH4          NH3          CO2          HCN          CO
   1       0.000       -1.000        0.000        0.000        0.000

RXN NO.     H2           O2           N2           H2O          H3O+
   1       0.000        0.000        0.000        0.000        0.000

RXN NO.     OH-          NH4+         H2PO4-01     HPO4--01
   1       0.000        1.000       -1.000        1.000

****    PROFILES   ****

 P-SPEC          STAGE   1  PRES, PSIA                       14.6959

                       ******************
                       ****  RESULTS  ****
                       ******************


***   COMPONENT SPLIT FRACTIONS   ***

                          OUTLET STREAMS
                          --------------
              13            14-15
 COMPONENT:
 CH4          1.0000       .68120E-06
 NH3          .99187       .81315E-02
 CO2          .99999       .11624E-04
```

```
    HCN          .99817       .18320E-02
    CO           .99997       .34923E-04
    H2           1.0000       .59842E-06
    O2           1.0000       .68154E-06
    N2           1.0000       .38849E-06
    H2O          .81773       .18227
    H3O+         0.0000       1.0000
    OH-          0.0000       1.0000
    NH4+         0.0000       1.0000
    H2PO4-01     0.0000       1.0000
    HPO4--01     0.0000       1.0000


   ***     SUMMARY OF KEY RESULTS    ***

    TOP STAGE TEMPERATURE          F                          156.818
    BOTTOM STAGE TEMPERATURE       F                          158.281
    TOP STAGE LIQUID FLOW          LBMOL/HR                   847.068
    BOTTOM STAGE LIQUID FLOW       LBMOL/HR                   706.559
    TOP STAGE VAPOR FLOW           LBMOL/HR                 5,661.24
    BOILUP VAPOR FLOW              LBMOL/HR                 5,582.37
    CONDENSER DUTY (W/O SUBCOOL)   BTU/HR                       0.0
    REBOILER DUTY                  BTU/HR                       0.0

   ****   MAXIMUM FINAL RELATIVE ERRORS   ****

    BUBBLE POINT                    0.79732E-05  STAGE=  1
    COMPONENT MASS BALANCE          0.16457E-08  STAGE=  1 COMP=NH3
    ENERGY BALANCE                  0.84812E-06  STAGE=  1


   ****    PROFILES   ****

   **NOTE** REPORTED VALUES FOR STAGE LIQUID AND VAPOR RATES ARE THE FLOWS
            FROM THE STAGE INCLUDING ANY SIDE PRODUCT.

                                               ENTHALPY
 STAGE TEMPERATURE   PRESSURE                  BTU/LBMOL           HEAT DUTY
       F             PSIA              LIQUID        VAPOR          BTU/HR

   1   156.82        14.696      -0.16174E+06  -34333.
   2   158.28        14.696      -0.16826E+06  -32232.

 STAGE     FLOW RATE                     FEED RATE                PRODUCT RATE
            LBMOL/HR                      LBMOL/HR                  LBMOL/HR
      LIQUID     VAPOR       LIQUID    VAPOR    MIXED       LIQUID    VAPOR
   1  847.1      5661.      925.9415
5661.2420
   2  706.6      5582.                               5441.8598   706.5592

    ****  MASS FLOW PROFILES  ****

 STAGE     FLOW RATE                     FEED RATE                PRODUCT RATE
            LB/HR                         LB/HR                     LB/HR
      LIQUID     VAPOR       LIQUID    VAPOR    MIXED       LIQUID    VAPOR
   1 0.2390E+05 0.1251E+06  .25389+05
.12511+06
   2 0.2135E+05 0.1236E+06                            .12107+06  .21347+05

                     ****   MOLE-X-PROFILE     ****
   STAGE     CH4           NH3           CO2           HCN           CO
      1    0.11973E-07   0.35365E-04   0.29984E-06   0.94142E-08   0.11496E-
04
```

2	0.10764E-07	0.16488E-03	0.26790E-06	0.83508E-08	0.10221E-04

**** MOLE-X-PROFILE ****

STAGE	H2	O2	N2	H2O	H3O+
1	0.58153E-06	0.10776E-06	0.17796E-05	0.65278	0.19716E-06
2	0.52543E-06	0.96999E-07	0.16052E-05	0.55914	0.23637E-06

**** MOLE-X-PROFILE ****

STAGE	OH-	NH4+	H2PO4-01	HPO4--01
1	0.19716E-06	0.21704	0.43225E-01	0.86908E-01
2	0.23637E-06	0.28467	0.27355E-01	0.12866

**** MOLE-Y-PROFILE ****

STAGE	CH4	NH3	CO2	HCN	CO
1	0.19721E-02	0.25101E-02	0.28765E-02	0.56461E-06	0.36526E-01
2	0.19999E-02	0.15738E-01	0.29172E-02	0.57402E-06	0.37044E-01

**** MOLE-Y-PROFILE ****

STAGE	H2	O2	N2	H2O	H3O+
1	0.10958	0.17763E-01	0.51569	0.31308	0.0000
2	0.11113	0.18014E-01	0.52298	0.29018	0.0000

**** MOLE-Y-PROFILE ****

STAGE	OH-	NH4+	H2PO4-01	HPO4--01
1	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000

**** K-VALUES ****

STAGE	CH4	NH3	CO2	HCN	CO
1	0.16471E+06	70.978	9593.5	59.975	3177.4
2	0.18580E+06	95.452	10889.	68.739	3624.3

**** K-VALUES ****

STAGE	H2	O2	N2	H2O	H3O+
1	0.18844E+06	0.16483E+06	0.28979E+06	0.47961	0.0000
2	0.21151E+06	0.18571E+06	0.32580E+06	0.51897	0.0000

**** K-VALUES ****

STAGE	OH-	NH4+	H2PO4-01	HPO4--01
1	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000

**** RATES OF GENERATION ****
LBMOL/HR

STAGE	CH4	NH3	CO2	HCN	CO	H2
1	0.000	-73.62	0.000	0.000	0.000	0.000
2	0.000	-17.29	0.000	0.000	0.000	0.000

**** RATES OF GENERATION ****
LBMOL/HR

STAGE	O2	N2	H2O	H3O+	OH-	NH4+
1	0.000	0.000	0.000	0.000	0.000	73.62
2	0.000	0.000	0.000	0.000	0.000	17.29

**** RATES OF GENERATION ****
LBMOL/HR

STAGE	H2PO4-01	HPO4--01
1	-73.62	73.62
2	-17.29	17.29

```
                         ****   MASS-X-PROFILE     ****
   STAGE     CH4           NH3           CO2           HCN           CO
     1     0.68091E-08   0.21350E-04   0.46779E-06   0.90191E-08   0.11415E-
04
     2     0.57154E-08   0.92942E-04   0.39025E-06   0.74699E-08   0.94759E-
05

                         ****   MASS-X-PROFILE     ****
   STAGE     H2            O2            N2            H2O           H3O+
     1     0.41556E-07   0.12224E-06   0.17672E-05   0.41688       0.13295E-
06
     2     0.35059E-07   0.10273E-06   0.14884E-05   0.33341       0.14882E-
06

                         ****   MASS-X-PROFILE     ****
   STAGE     OH-           NH4+          H2PO4-01      HPO4--01
     1     0.11887E-06   0.13878       0.14861       0.29569
     2     0.13306E-06   0.16996       0.87815E-01   0.40872

                         ****   MASS-Y-PROFILE     ****
   STAGE     CH4           NH3           CO2           HCN           CO
     1     0.14316E-02   0.19343E-02   0.57283E-02   0.69046E-06   0.46295E-
01
     2     0.14488E-02   0.12104E-01   0.57976E-02   0.70054E-06   0.46856E-
01

                         ****   MASS-Y-PROFILE     ****
   STAGE     H2            O2            N2            H2O           H3O+
     1     0.99959E-02   0.25719E-01   0.65368       0.25521        0.0000
     2     0.10117E-01   0.26030E-01   0.66158       0.23607        0.0000

                         ****   MASS-Y-PROFILE     ****
   STAGE     OH-           NH4+          H2PO4-01      HPO4--01
     1      0.0000        0.0000        0.0000        0.0000
     2      0.0000        0.0000        0.0000        0.0000

 BLOCK:  V-102    MODEL: RADFRAC
 -------------------------------
    INLETS   - 14-15    STAGE   1
               19       STAGE   2
    OUTLETS  - 20       STAGE   1
               16       STAGE   2
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                       ***  MASS AND ENERGY BALANCE  ***
                                 IN          OUT       GENERATION   RELATIVE
DIFF.
   TOTAL BALANCE
   MOLE(LBMOL/HR)         926.835       926.835     -0.137679E-13  0.159460E-
14
   MASS(LB/HR   )         25315.4       25315.4                   -0.273350E-
10
   ENTHALPY(BTU/HR  )   -0.141237E+09 -0.141237E+09               -0.295206E-
05

                       ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.113808E-01  LB/HR
    PRODUCT STREAMS CO2E         0.113808E-01  LB/HR
    NET STREAMS CO2E PRODUCTION -0.944317E-10  LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION       -0.944317E-10  LB/HR
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                    ********************
                    ****  INPUT DATA  ****
                    ********************

   ****    INPUT PARAMETERS    ****

    NUMBER OF STAGES                                         2
    ALGORITHM OPTION                                        STANDARD
    INITIALIZATION OPTION                                   STANDARD
    HYDRAULIC PARAMETER CALCULATIONS                        NO
    INSIDE LOOP CONVERGENCE METHOD                          NEWTON
    DESIGN SPECIFICATION METHOD                             NESTED
    MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS                    25
    MAXIMUM NO. OF INSIDE LOOP ITERATIONS                     10
    MAXIMUM NUMBER OF FLASH ITERATIONS                        30
    FLASH TOLERANCE                                          0.000100000
    OUTSIDE LOOP CONVERGENCE TOLERANCE                       0.000100000

   ****    COL-SPECS    ****

    MOLAR VAPOR DIST / TOTAL DIST                            1.00000
    CONDENSER DUTY (W/O SUBCOOL)   BTU/HR                    0.0
    REBOILER DUTY                  BTU/HR                    0.0

   **** REAC-STAGES SPECIFICATIONS ****

    STAGE  TO  STAGE          REACTIONS/CHEMISTRY ID
      1          2                    PHOSDEC


        *****  REACTION PARAGRAPH PHOSDEC *****


          ****  REACTION PARAMETERS  ****

   RXN NO. TYPE          PHASE      CONC.    TEMP APP TO EQUIL    CONVERSION
                                    BASIS           F
     1    CONVERSION                                              SIMULTANEOUS

        **  STOICHIOMETRIC COEFFICIENTS  **

   RXN NO.     CH4          NH3          CO2          HCN          CO
     1         0.000        1.000        0.000        0.000        0.000

   RXN NO.     H2           O2           N2           H2O          H3O+
     1         0.000        0.000        0.000        0.000        0.000

   RXN NO.     CN-          OH-          NH4+         H2PO4-01     HPO4--01
     1         0.000        0.000       -1.000        1.000       -1.000

        ** COEFFICIENTS OF CONVERSION EXPRESSION **

   RXN NO.    COMPONENT ID    A             B             C             D
     1        HPO4--01       1.0000        0.0000        0.0000
0.0000

   ****     PROFILES    ****

    P-SPEC          STAGE   1  PRES, PSIA                   14.6959

                     ******************
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**** RESULTS ****
****

*** COMPONENT SPLIT FRACTIONS ***

	OUTLET STREAMS	
	20	16
COMPONENT:		
CH4	1.0000	0.0000
NH3	.98856	.11444E-01
CO2	1.0000	.52015E-06
HCN	.93895	.61048E-01
CO	1.0000	.42811E-05
H2	1.0000	0.0000
O2	1.0000	0.0000
N2	1.0000	0.0000
H2O	.70362E-01	.92964
H3O+	0.0000	1.0000
CN-	0.0000	1.0000
OH-	0.0000	1.0000
NH4+	0.0000	1.0000
H2PO4-01	0.0000	1.0000
HPO4--01	MISSING	MISSING

*** SUMMARY OF KEY RESULTS ***

TOP STAGE TEMPERATURE	F	149.913
BOTTOM STAGE TEMPERATURE	F	190.051
TOP STAGE LIQUID FLOW	LBMOL/HR	828.121
BOTTOM STAGE LIQUID FLOW	LBMOL/HR	793.551
TOP STAGE VAPOR FLOW	LBMOL/HR	133.283
BOILUP VAPOR FLOW	LBMOL/HR	254.845
CONDENSER DUTY (W/O SUBCOOL)	BTU/HR	0.0
REBOILER DUTY	BTU/HR	0.0

**** MAXIMUM FINAL RELATIVE ERRORS ****

BUBBLE POINT	0.10735E-03	STAGE= 1	
COMPONENT MASS BALANCE	0.12005E-06	STAGE= 2	COMP=NH3
ENERGY BALANCE	0.43089E-04	STAGE= 2	

**** PROFILES ****

NOTE REPORTED VALUES FOR STAGE LIQUID AND VAPOR RATES ARE THE FLOWS
FROM THE STAGE INCLUDING ANY SIDE PRODUCT.

STAGE	TEMPERATURE F	PRESSURE PSIA	ENTHALPY BTU/LBMOL LIQUID	ENTHALPY BTU/LBMOL VAPOR	HEAT DUTY BTU/HR
1	149.91	14.696	-0.16631E+06	-46473.	
2	190.05	14.696	-0.17018E+06	-98224.	

STAGE	FLOW RATE LBMOL/HR LIQUID	FLOW RATE LBMOL/HR VAPOR	FEED RATE LBMOL/HR LIQUID	FEED RATE LBMOL/HR VAPOR	FEED RATE LBMOL/HR MIXED	PRODUCT RATE LBMOL/HR LIQUID	PRODUCT RATE LBMOL/HR VAPOR
1	828.1	133.3	706.5592				
133.2833							
2	793.6	254.8			220.2752	793.5512	

**** MASS FLOW PROFILES ****

```
 STAGE     FLOW RATE                    FEED RATE                 PRODUCT RATE
            LB/HR                         LB/HR                      LB/HR
       LIQUID      VAPOR       LIQUID    VAPOR    MIXED       LIQUID    VAPOR
   1 0.2361E+05  2313.      .21347+05
2312.6168
   2 0.2300E+05  4576.                            3968.3207  .23003+05
```

**** MOLE-X-PROFILE ****

STAGE	CH4	NH3	CO2	HCN	CO
1	0.55723E-12	0.19212E-01	0.24488E-09	0.11494E-08	0.28888E-07
2	0.18942E-16	0.13126E-02	0.12407E-12	0.71937E-10	0.38960E-10

**** MOLE-X-PROFILE ****

STAGE	H2	O2	N2	H2O	H3O+
1	0.23214E-10	0.49911E-11	0.46521E-10	0.71457	0.15676E-07
2	0.75447E-15	0.17262E-15	0.95496E-15	0.72087	0.16359E-07

**** MOLE-X-PROFILE ****

STAGE	CN-	OH-	NH4+	H2PO4-01	HPO4--01
1	0.63462E-09	0.15041E-07	0.13311	0.13311	0.13876E-32
2	0.66226E-09	0.15697E-07	0.13891	0.13891	0.0000

**** MOLE-Y-PROFILE ****

STAGE	CH4	NH3	CO2	HCN	CO
1	0.57060E-07	0.67509	0.14202E-05	0.39898E-07	0.54183E-04
2	0.18106E-11	0.58342E-01	0.79537E-09	0.35109E-08	0.93750E-07

**** MOLE-Y-PROFILE ****

STAGE	H2	O2	N2	H2O	H3O+
1	0.27854E-05	0.51421E-06	0.85095E-05	0.32485	0.0000
2	0.75433E-10	0.16218E-10	0.15117E-09	0.94166	0.0000

**** MOLE-Y-PROFILE ****

STAGE	CN-	OH-	NH4+	H2PO4-01	HPO4--01
1	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000

**** K-VALUES ****

STAGE	CH4	NH3	CO2	HCN	CO
1	0.10239E+06	35.134	5798.9	34.709	1875.5
2	95583.	44.448	6410.1	48.804	2406.2

**** K-VALUES ****

STAGE	H2	O2	N2	H2O	H3O+
1	0.11997E+06	0.10301E+06	0.18289E+06	0.45459	0.0000
2	99976.	93951.	0.15829E+06	1.3063	0.0000

**** K-VALUES ****

STAGE	CN-	OH-	NH4+	H2PO4-01	HPO4--01
1	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000

**** RATES OF GENERATION ****

LBMOL/HR

STAGE	CH4	NH3	CO2	HCN	CO	H2

1	0.000	90.90	0.000	0.000	0.000	0.000
2	0.000	0.1149E-29	0.000	0.000	0.000	0.000

**** RATES OF GENERATION ****
LBMOL/HR

STAGE	O2	N2	H2O	H3O+	CN-	OH-
1	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000

**** RATES OF GENERATION ****
LBMOL/HR

STAGE	NH4+	H2PO4-01	HPO4--01
1	-90.90	90.90	-90.90
2	-.1149E-29	0.1149E-29	-.1149E-29

**** MASS-X-PROFILE ****

STAGE	CH4	NH3	CO2	HCN	CO
1	0.31354E-12	0.11476E-01	0.37800E-09	0.10895E-08	0.28380E-07
2	0.10484E-16	0.77116E-03	0.18838E-12	0.67070E-10	0.37647E-10

**** MASS-X-PROFILE ****

STAGE	H2	O2	N2	H2O	H3O+
1	0.16414E-11	0.56016E-11	0.45708E-10	0.45151	0.10459E-07
2	0.52469E-16	0.19055E-15	0.92289E-15	0.44802	0.10735E-07

**** MASS-X-PROFILE ****

STAGE	CN-	OH-	NH4+	H2PO4-01	HPO4--01
1	0.57912E-09	0.89727E-08	0.84213E-01	0.45280	0.46712E-32
2	0.59443E-09	0.92099E-08	0.86439E-01	0.46477	0.0000

**** MASS-Y-PROFILE ****

STAGE	CH4	NH3	CO2	HCN	CO
1	0.52757E-07	0.66261	0.36022E-05	0.62144E-07	0.87469E-04
2	0.16176E-11	0.55330E-01	0.19492E-08	0.52838E-08	0.14623E-06

**** MASS-Y-PROFILE ****

STAGE	H2	O2	N2	H2O	H3O+
1	0.32361E-06	0.94830E-06	0.13739E-04	0.33728	0.0000
2	0.84678E-11	0.28899E-10	0.23581E-09	0.94467	0.0000

**** MASS-Y-PROFILE ****

STAGE	CN-	OH-	NH4+	H2PO4-01	HPO4--01
1	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000

Appendix D.3: Stream Report

1-5 10 11 12 13

STREAM ID	1-5	10	11	12	13
FROM :	----	E100B	E-102	V-100	V-101
TO :	MIX1	E-102	V-100	V-101	----
CLASS:	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD
TOTAL STREAM:					
LB/HR	1.2300+05	1.2532+05	1.2532+05	1.2107+05	1.2511+05
BTU/HR	-3.1973+07	-1.0656+08	-1.1334+08	-1.6181+08	-1.9437+08
SUBSTREAM: MIXED					
PHASE:	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR
COMPONENTS: LBMOL/HR					
CH4	590.8389	11.1643	11.1643	11.1643	11.1643
NH3	496.0401	105.4832	105.4832	105.2297	14.2103
CO2	0.0	21.2704	21.2704	16.2848	16.2846
HCN	0.0	351.6108	351.6108	3.2023-03	3.1964-03
CO	0.0	206.8008	206.8008	206.7907	206.7835
H2	0.0	620.3812	620.3812	620.3805	620.3801
O2	767.2087	100.5592	100.5592	100.5591	100.5590
N2	2854.9863	2919.4494	2919.4494	2919.4473	2919.4462
H2O	30.5120	1157.7684	1157.7684	1462.0003	1772.4109
NAOH	0.0	0.0	0.0	0.0	0.0
H3O+	0.0	0.0	0.0	0.0	0.0
NA+	0.0	0.0	0.0	0.0	0.0
CN-	0.0	0.0	0.0	0.0	0.0
OH-	0.0	0.0	0.0	0.0	0.0
NACN(S)	0.0	0.0	0.0	0.0	0.0
NAOH:(S)	0.0	0.0	0.0	0.0	0.0
NAOH(S)	0.0	0.0	0.0	0.0	0.0
CO3--	0.0	0.0	0.0	0.0	0.0
HCO3-	0.0	0.0	0.0	0.0	0.0
SODIU-01	0.0	0.0	0.0	0.0	0.0
SODIU-02	0.0	0.0	0.0	0.0	0.0
AMMON-01	0.0	0.0	0.0	0.0	0.0
DIAMM-01	0.0	0.0	0.0	0.0	0.0
NH4+	0.0	0.0	0.0	0.0	0.0
H2PO4-01	0.0	0.0	0.0	0.0	0.0
HPO4--01	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	4739.5859	5494.4877	5494.4877	5441.8598	5661.2421
LB/HR	1.2300+05	1.2532+05	1.2532+05	1.2107+05	1.2511+05
CUFT/HR	1.8553+06	1.9734+06	2.4742+06	2.6640+06	2.5441+06
STATE VARIABLES:					
TEMP F	77.0000	324.0483	158.0000	211.4760	156.8182
PRES PSIA	14.6959	23.3919	14.6959	14.6959	14.6959
VFRAC	1.0000	1.0000	1.0000	1.0000	1.0000
LFRAC	0.0	0.0	0.0	0.0	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-6746.0164	-1.9394+04	-2.0629+04	-2.9734+04	-3.4333+04
BTU/LB	-259.9371	-850.3107	-904.4625	-1336.4816	-1553.5276
BTU/HR	-3.1973+07	-1.0656+08	-1.1334+08	-1.6181+08	-1.9437+08
ENTROPY:					
BTU/LBMOL-R	-2.7123	3.2563	2.4078	1.5597	0.7266
BTU/LB-R	-0.1045	0.1428	0.1056	7.0107-02	3.2876-02
DENSITY:					
LBMOL/CUFT	2.5546-03	2.7843-03	2.2207-03	2.0427-03	2.2252-03
LB/CUFT	6.6299-02	6.3503-02	5.0650-02	4.5447-02	4.9177-02
AVG MW	25.9525	22.8077	22.8077	22.2481	22.0999

14-15 16 18 19 20

STREAM ID	14-15	16	18	19	20
FROM :	V-101	V-102	----	----	V-102
TO :	V-102	----	V-101	V-102	MIX1
CLASS:	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD
TOTAL STREAM:					
LB/HR	2.1347+04	2.3003+04	2.5389+04	3968.3207	2312.6169
BTU/HR	-1.1888+08	-1.3504+08	-1.5144+08	-2.2354+07	-6.1940+06
SUBSTREAM: MIXED					
PHASE:	LIQUID	MIXED	LIQUID	VAPOR	VAPOR
COMPONENTS: LBMOL/HR					
CH4	7.6051-06	0.0	0.0	0.0	7.6051-06
NH3	0.1165	1.0416	0.0	0.0	89.9778
CO2	1.8929-04	9.8460-11	0.0	0.0	1.8929-04
HCN	5.8667-06	3.4574-07	0.0	0.0	5.3177-06
CO	7.2217-03	3.0917-08	0.0	0.0	7.2217-03
H2	3.7125-04	0.0	0.0	0.0	3.7125-04
O2	6.8535-05	0.0	0.0	0.0	6.8535-05
N2	1.1342-03	0.0	0.0	0.0	1.1342-03
H2O	395.0686	572.0466	705.4789	220.2753	43.2965
NAOH	0.0	0.0	0.0	0.0	0.0
H3O+	1.6593-07	4.0637-04	1.6741-04	0.0	0.0
NA+	0.0	0.0	0.0	0.0	0.0
CN-	3.3657-08	2.3688-07	0.0	0.0	0.0
OH-	1.3227-07	4.0614-04	1.6741-04	0.0	0.0
NACN(S)	0.0	0.0	0.0	0.0	0.0
NAOH:(S)	0.0	0.0	0.0	0.0	0.0
NAOH(S)	0.0	0.0	0.0	0.0	0.0
CO3--	0.0	0.0	0.0	0.0	0.0
HCO3-	0.0	0.0	0.0	0.0	0.0
SODIU-01	0.0	0.0	0.0	0.0	0.0
SODIU-02	0.0	0.0	0.0	0.0	0.0
AMMON-01	0.0	0.0	0.0	0.0	0.0
DIAMM-01	0.0	0.0	0.0	0.0	0.0
NH4+	201.1341	110.2311	110.2311	0.0	0.0
H2PO4-01	19.3282	110.2311	110.2311	0.0	0.0
HPO4--01	90.9029	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	706.5593	793.5512	925.9415	220.2753	133.2833
LB/HR	2.1347+04	2.3003+04	2.5389+04	3968.3207	2312.6169
CUFT/HR	204.2474	276.3248	303.0923	1.3648+05	5.8953+04
STATE VARIABLES:					
TEMP F	-5.3989-02	190.0521	158.0000	392.0000	149.9129
PRES PSIA	14.6959	14.6959	14.6959	14.6959	14.6959
VFRAC	0.0	2.2242-05	0.0	1.0000	1.0000
LFRAC	1.0000	1.0000	1.0000	0.0	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-1.6826+05	-1.7017+05	-1.6355+05	-1.0148+05	-4.6473+04
BTU/LB	-5569.0833	-5870.7123	-5964.8440	-5632.9893	-2678.3688
BTU/HR	-1.1888+08	-1.3504+08	-1.5144+08	-2.2354+07	-6.1940+06
ENTROPY:					
BTU/LBMOL-R	-50.9124	-44.6361	-43.9290	-6.8383	-17.1172
BTU/LB-R	-1.6851	-1.5399	-1.6021	-0.3796	-0.9865
DENSITY:					
LBMOL/CUFT	3.4593	2.8718	3.0550	1.6140-03	2.2609-03
LB/CUFT	104.5156	83.2453	83.7660	2.9077-02	3.9228-02
AVG MW	30.2127	28.9871	27.4195	18.0153	17.3511

21 22 22-23 23 24

STREAM ID	21	22	22-23	23	24
FROM :	----	V-100	E-103	E-103HX	MIX2
TO :	V-100	E-103	E-103HX	MIX2	SEP-100
CLASS:	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD
TOTAL STREAM:					
LB/HR	2.9432+04	3.3677+04	3.3255+04	3.3255+04	1.0173+05
BTU/HR	-1.7068+08	-1.2221+08	-1.2024+08	-1.2011+08	-4.5090+08
SUBSTREAM: MIXED					
PHASE:	LIQUID	LIQUID	MIXED	MIXED	LIQUID
COMPONENTS: LBMOL/HR					
CH4	0.0	1.3458-05	1.3458-05	1.3458-05	1.3458-05
NH3	0.0	0.2535	0.2535	0.2535	0.2540
CO2	0.0	3.3919-04	3.3919-04	3.3919-04	3.3919-04
HCN	0.0	4.0140-03	4.0983-03	4.5851-03	1.4913-04
CO	0.0	1.0126-02	1.0126-02	1.0126-02	1.0126-02
H2	0.0	7.0812-04	7.0812-04	7.0812-04	7.0812-04
O2	0.0	1.2311-04	1.2311-04	1.2311-04	1.2311-04
N2	0.0	2.1135-03	2.1135-03	2.1135-03	2.1135-03
H2O	816.8541	869.2101	869.2101	869.2096	2791.9291
NAOH	0.0	0.0	0.0	0.0	0.0
H3O+	1.4041-15	7.9413-12	8.1295-12	1.0687-11	1.1926-13
NA+	367.9230	367.9230	359.9466	359.9466	1125.9079
CN-	0.0	351.6036	351.6035	351.6030	693.7436
OH-	367.9230	6.3499	6.3499	6.3504	423.6449
NACN(S)	0.0	0.0	0.0	0.0	0.0
NAOH:(S)	0.0	0.0	0.0	0.0	0.0
NAOH(S)	0.0	0.0	0.0	0.0	0.0
CO3--	0.0	4.9843	0.9969	0.9969	4.8801
HCO3-	0.0	9.4715-04	1.8943-04	1.8943-04	1.2627-02
SODIU-01	0.0	0.0	0.0	0.0	0.0
SODIU-02	0.0	0.0	0.0	0.0	0.0
AMMON-01	0.0	0.0	0.0	0.0	0.0
DIAMM-01	0.0	0.0	0.0	0.0	0.0
NH4+	0.0	0.0	0.0	0.0	0.0
H2PO4-01	0.0	0.0	0.0	0.0	0.0
HPO4--01	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	1552.7001	1600.3428	1588.3782	1588.3782	5040.3859
LB/HR	2.9432+04	3.3677+04	3.3255+04	3.3255+04	1.0173+05
CUFT/HR	315.0386	842.1076	840.1798	843.3449	2036.2787
STATE VARIABLES:					
TEMP F	158.0000	187.1619	187.1619	196.1619	156.6218
PRES PSIA	14.6959	14.6959	14.6959	14.6959	14.6959
VFRAC	0.0	0.0	2.3432-08	3.1836-07	0.0
LFRAC	1.0000	1.0000	1.0000	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-1.0992+05	-7.6365+04	-7.5701+04	-7.5616+04	-8.9458+04
BTU/LB	-5799.0469	-3628.8648	-3615.7691	-3611.7327	-4432.1465
BTU/HR	-1.7068+08	-1.2221+08	-1.2024+08	-1.2011+08	-4.5090+08
ENTROPY:					
BTU/LBMOL-R	-28.1553	-20.6638	-20.6289	-20.4992	-23.8765
BTU/LB-R	-1.4854	-0.9819	-0.9853	-0.9791	-1.1829
DENSITY:					
LBMOL/CUFT	4.9286	1.9004	1.8905	1.8834	2.4753
LB/CUFT	93.4226	39.9918	39.5805	39.4319	49.9611
AVG MW	18.9552	21.0439	20.9363	20.9363	20.1839

25 26 28 29 30

STREAM ID	25	26	28	29	30
FROM :	SEP-100	SEP-100	P-101	SEP-101	SEP-101
TO :	P-101	----	SEP-101	MIX2	SEP-102

CLASS:	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD
CONV. MAX. REL. ERR:	0.0	0.0	0.0	-7.0967-05	0.0
TOTAL STREAM:					
LB/HR	8.6599+04	1.5136+04	8.6599+04	6.8480+04	1.8118+04
BTU/HR	-3.4896+08	-8.6962+07	-3.4896+08	-3.3080+08	-1.8153+07
SUBSTREAM: MIXED					
PHASE:	LIQUID	VAPOR	MIXED	MIXED	MIXED
COMPONENTS: LBMOL/HR					
CH4	1.2339-11	1.3458-05	1.3153-11	1.2950-11	0.0
NH3	4.8699-04	0.2535	4.8699-04	4.7940-04	7.3049-06
CO2	5.7467-09	3.3919-04	5.7467-09	5.6572-09	8.6200-11
HCN	3.1818-05	1.0354-02	3.1858-05	3.1386-05	4.7795-07
CO	5.4285-07	1.0126-02	5.4285-07	5.3440-07	8.1428-09
H2	5.2810-10	7.0812-04	5.2810-10	5.1994-10	0.0
O2	1.1095-10	1.2311-04	1.1095-10	1.0923-10	0.0
N2	1.0574-09	2.1135-03	1.0574-09	1.0412-09	1.5861-11
H2O	1952.0236	839.8953	1952.0236	1922.7151	29.2804
NAOH	0.0	0.0	0.0	0.0	0.0
H3O+	1.6806-14	0.0	1.6866-14	1.6622-14	2.5312-16
NA+	777.6379	0.0	777.6351	765.9608	11.6645
CN-	347.3360	0.0	347.3360	342.1361	5.2100
OH-	423.6551	0.0	423.6551	417.2989	6.3548
NACN(S)	0.0	0.0	0.0	0.0	0.0
NAOH:(S)	0.0	0.0	0.0	0.0	0.0
NAOH(S)	0.0	0.0	0.0	0.0	0.0
CO3--	3.9438	0.0	3.9424	3.8830	5.9128-02
HCO3-	1.2627-02	0.0	1.2627-02	1.2438-02	1.8941-04
SODIU-01	0.0	0.0	0.0	0.0	0.0
SODIU-02	0.9363	0.0	0.9377	2.7142-04	0.9378
AMMON-01	0.0	0.0	0.0	0.0	0.0
DIAMM-01	0.0	0.0	0.0	0.0	0.0
NH4+	0.0	0.0	0.0	0.0	0.0
H2PO4-01	0.0	0.0	0.0	0.0	0.0
HPO4--01	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	3505.5459	840.1726	3505.5430	3452.0071	53.5068
LB/HR	6.9623+04	1.5136+04	6.9623+04	6.8480+04	1142.2412
CUFT/HR	1217.3461	6.0033+06	1217.5366	1198.6506	18.8823
STATE VARIABLES:					
TEMP F	140.0000	140.0000	140.0834	140.0970	140.0970
PRES PSIA	0.9001	0.9001	14.5038	14.6959	14.6959
VFRAC	0.0	1.0000	0.0	0.0	0.0
LFRAC	1.0000	0.0	0.9997	1.0000	0.9825
SFRAC	0.0	0.0	2.6750-04	1.5328-07	1.7526-02
ENTHALPY:					
BTU/LBMOL	-9.5814+04	-1.0351+05	-9.5932+04	-9.5827+04	-1.0263+05
BTU/LB	-4824.2890	-5745.4326	-4830.2187	-4830.5510	-4807.4212
BTU/HR	-3.3588+08	-8.6962+07	-3.3629+08	-3.3080+08	-5.4912+06
ENTROPY:					
BTU/LBMOL-R	-26.8566	-4.1566	-25.5814	-25.5706	-26.2591
BTU/LB-R	-1.3522	-0.2307	-1.2880	-1.2890	-1.2301
DENSITY:					
LBMOL/CUFT	2.8797	1.3995-04	2.8792	2.8799	2.8337
LB/CUFT	57.1923	2.5213-03	57.1833	57.1310	60.4926
AVG MW	19.8608	18.0152	19.8608	19.8378	21.3476
SUBSTREAM: CISOLID	STRUCTURE: CONVENTIONAL				
COMPONENTS: LBMOL/HR					
CH4	0.0	0.0	0.0	0.0	0.0
NH3	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
HCN	0.0	0.0	0.0	0.0	0.0
CO	0.0	0.0	0.0	0.0	0.0

H2	0.0	0.0	0.0	0.0	0.0
O2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
H2O	0.0	0.0	0.0	0.0	0.0
NAOH	0.0	0.0	0.0	0.0	0.0
H3O+	0.0	0.0	0.0	0.0	0.0
NA+	0.0	0.0	0.0	0.0	0.0
CN-	0.0	0.0	0.0	0.0	0.0
OH-	0.0	0.0	0.0	0.0	0.0
NACN(S)	346.3974	0.0	346.3974	0.0	346.3974
NAOH:(S)	0.0	0.0	0.0	0.0	0.0
NAOH(S)	0.0	0.0	0.0	0.0	0.0
CO3--	0.0	0.0	0.0	0.0	0.0
HCO3-	0.0	0.0	0.0	0.0	0.0
SODIU-01	0.0	0.0	0.0	0.0	0.0
SODIU-02	0.0	0.0	0.0	0.0	0.0
AMMON-01	0.0	0.0	0.0	0.0	0.0
DIAMM-01	0.0	0.0	0.0	0.0	0.0
NH4+	0.0	0.0	0.0	0.0	0.0
H2PO4-01	0.0	0.0	0.0	0.0	0.0
HPO4--01	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	346.3974	0.0	346.3974	0.0	346.3974
LB/HR	1.6976+04	0.0	1.6976+04	0.0	1.6976+04
CUFT/HR	166.6399	0.0	166.4626	0.0	166.4626
STATE VARIABLES:					
TEMP F	140.0000	MISSING	140.0834	MISSING	140.0970
PRES PSIA	0.9001	MISSING	14.5038	MISSING	14.6959
VFRAC	0.0	MISSING	0.0	MISSING	0.0
LFRAC	0.0	MISSING	0.0	MISSING	0.0
SFRAC	1.0000	MISSING	1.0000	MISSING	1.0000
ENTHALPY:					
BTU/LBMOL	-3.7761+04	MISSING	-3.6554+04	MISSING	-3.6553+04
BTU/LB	-770.5065	MISSING	-745.8785	MISSING	-745.8739
BTU/HR	-1.3080+07	MISSING	-1.2662+07	MISSING	-1.2662+07
ENTROPY:					
BTU/LBMOL-R	-7.1505	MISSING	-6.9922	MISSING	-6.9918
BTU/LB-R	-0.1459	MISSING	-0.1427	MISSING	-0.1427
DENSITY:					
LBMOL/CUFT	2.0787	MISSING	2.0809	MISSING	2.0809
LB/CUFT	101.8728	MISSING	101.9813	MISSING	101.9813
AVG MW	49.0075	MISSING	49.0075	MISSING	49.0075

31 32 33 34 35

STREAM ID	31	32	33	34	35
FROM :	----	E-105	E-105	P-102	E-106
TO :	E-105	P-102	----	E-106	----
CLASS:	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD
TOTAL STREAM:					
LB/HR	2.2430+04	2.1958+04	471.7892	2.1958+04	2.1958+04
BTU/HR	-1.1293+07	-8.6765+06	-3.1989+06	-8.0669+06	-7.7060+06
SUBSTREAM: MIXED					
PHASE:	VAPOR	VAPOR	LIQUID	VAPOR	VAPOR
COMPONENTS: LBMOL/HR					
CH4	0.0	0.0	0.0	0.0	0.0
NH3	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
HCN	0.0	0.0	0.0	0.0	0.0
CO	0.0	0.0	0.0	0.0	0.0
H2	0.0	0.0	0.0	0.0	0.0
O2	489.3412	489.3412	0.0	489.3412	489.3412
N2	169.7923	169.7923	0.0	169.7923	169.7923

H2O	111.8509	85.6626	26.1883	85.6626	85.6626
NAOH	0.0	0.0	0.0	0.0	0.0
H3O+	0.0	0.0	1.0950-07	0.0	0.0
NA+	0.0	0.0	0.0	0.0	0.0
CN-	0.0	0.0	0.0	0.0	0.0
OH-	0.0	0.0	1.0950-07	0.0	0.0
NACN(S)	0.0	0.0	0.0	0.0	0.0
NAOH:(S)	0.0	0.0	0.0	0.0	0.0
NAOH(S)	0.0	0.0	0.0	0.0	0.0
CO3--	0.0	0.0	0.0	0.0	0.0
HCO3-	0.0	0.0	0.0	0.0	0.0
SODIU-01	0.0	0.0	0.0	0.0	0.0
SODIU-02	0.0	0.0	0.0	0.0	0.0
AMMON-01	0.0	0.0	0.0	0.0	0.0
DIAMM-01	0.0	0.0	0.0	0.0	0.0
NH4+	0.0	0.0	0.0	0.0	0.0
H2PO4-01	0.0	0.0	0.0	0.0	0.0
HPO4--01	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	770.9844	744.7961	26.1883	744.7961	744.7961
LB/HR	2.2430+04	2.1958+04	471.7892	2.1958+04	2.1958+04
CUFT/HR	2.7999+05	3.1601+05	7.6485	2.3435+05	2.9402+05
STATE VARIABLES:					
TEMP F	140.0000	122.0000	122.0000	235.7126	302.0000
PRES PSIA	17.6959	14.6959	14.6959	23.6959	20.6959
VFRAC	1.0000	1.0000	0.0	1.0000	1.0000
LFRAC	0.0	0.0	1.0000	0.0	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-1.4647+04	-1.1650+04	-1.2215+05	-1.0831+04	-1.0346+04
BTU/LB	-503.4772	-395.1408	-6780.4292	-367.3763	-350.9430
BTU/HR	-1.1293+07	-8.6765+06	-3.1989+06	-8.0669+06	-7.7060+06
ENTROPY:					
BTU/LBMOL-R	0.6739	1.0614	-37.5232	1.3987	2.3328
BTU/LB-R	2.3164-02	3.6001-02	-2.0829	4.7442-02	7.9126-02
DENSITY:					
LBMOL/CUFT	2.7536-03	2.3569-03	3.4240	3.1781-03	2.5332-03
LB/CUFT	8.0110-02	6.9486-02	61.6836	9.3696-02	7.4683-02
AVG MW	29.0925	29.4819	18.0153	29.4819	29.4819

36 6 7 8 9

STREAM ID	36	6	7	8	9
FROM :	SEP-102	MIX1	E-100A	R-100	E-101
TO :	----	E-100A	R-100	E-101	E100B
CLASS:	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD
CONV. MAX. REL. ERR:	0.0	6.9289-05	0.0	0.0	0.0
TOTAL STREAM:					
LB/HR	1.7647+04	1.2532+05	1.2532+05	1.2532+05	1.2532+05
BTU/HR	-1.4920+07	-3.8167+07	-2.6526+07	-2.6435+07	-9.4917+07
SUBSTREAM: MIXED					
PHASE:	MIXED	VAPOR	VAPOR	VAPOR	VAPOR
COMPONENTS: LBMOL/HR					
CH4	0.0	590.8389	590.8389	11.1643	11.1643
NH3	7.3049-06	586.0180	586.0180	105.4832	105.4832
CO2	8.6200-11	1.8930-04	1.8930-04	21.2704	21.2704
HCN	1.4997-10	5.3175-06	5.3175-06	351.6108	351.6108
CO	8.1428-09	7.2219-03	7.2219-03	206.8008	206.8008
H2	0.0	3.7127-04	3.7127-04	620.3812	620.3812
O2	0.0	767.2087	767.2087	100.5592	100.5592
N2	1.5861-11	2854.9874	2854.9874	2919.4494	2919.4494
H2O	3.0921	73.8034	73.8034	1157.7684	1157.7684

NAOH	0.0	0.0	0.0	0.0	0.0
H3O+	4.6024-20	0.0	0.0	0.0	0.0
NA+	6.4965	0.0	0.0	0.0	0.0
CN-	0.1597	0.0	0.0	0.0	0.0
OH-	6.3548	0.0	0.0	0.0	0.0
NACN(S)	5.0504	0.0	0.0	0.0	0.0
NAOH:(S)	0.0	0.0	0.0	0.0	0.0
NAOH(S)	0.0	0.0	0.0	0.0	0.0
CO3--	2.9504-04	0.0	0.0	0.0	0.0
HCO3-	1.8941-04	0.0	0.0	0.0	0.0
SODIU-01	0.0	0.0	0.0	0.0	0.0
SODIU-02	0.9966	0.0	0.0	0.0	0.0
AMMON-01	0.0	0.0	0.0	0.0	0.0
DIAMM-01	0.0	0.0	0.0	0.0	0.0
NH4+	0.0	0.0	0.0	0.0	0.0
H2PO4-01	0.0	0.0	0.0	0.0	0.0
HPO4--01	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	22.1505	4872.8642	4872.8642	5494.4877	5494.4877
LB/HR	670.4520	1.2532+05	1.2532+05	1.2532+05	1.2532+05
CUFT/HR	6.2428	1.9153+06	3.8076+06	5.0539+06	2.3688+06
STATE VARIABLES:					
TEMP F	140.0970	79.2778	392.0000	2058.8000	600.8000
PRES PSIA	14.6959	14.6959	11.6959	29.3919	26.3919
VFRAC	0.0	1.0000	1.0000	1.0000	1.0000
LFRAC	0.7270	0.0	0.0	0.0	0.0
SFRAC	0.2730	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-1.0194+05	-7832.5269	-5443.5390	-4811.1235	-1.7275+04
BTU/LB	-3367.7626	-304.5633	-211.6689	-210.9430	-757.4163
BTU/HR	-2.2579+06	-3.8167+07	-2.6526+07	-2.6435+07	-9.4917+07
ENTROPY:					
BTU/LBMOL-R	-21.1959	-2.9783	0.9613	12.4253	5.3299
BTU/LB-R	-0.7003	-0.1158	3.7380-02	0.5448	0.2337
DENSITY:					
LBMOL/CUFT	3.5482	2.5441-03	1.2798-03	1.0872-03	2.3196-03
LB/CUFT	107.3968	6.5428-02	3.2912-02	2.4796-02	5.2904-02
AVG MW	30.2681	25.7172	25.7172	22.8077	22.8077

SUBSTREAM: CISOLID STRUCTURE: CONVENTIONAL

COMPONENTS: LBMOL/HR					
CH4	0.0	0.0	0.0	0.0	0.0
NH3	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
HCN	0.0	0.0	0.0	0.0	0.0
CO	0.0	0.0	0.0	0.0	0.0
H2	0.0	0.0	0.0	0.0	0.0
O2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
H2O	0.0	0.0	0.0	0.0	0.0
NAOH	0.0	0.0	0.0	0.0	0.0
H3O+	0.0	0.0	0.0	0.0	0.0
NA+	0.0	0.0	0.0	0.0	0.0
CN-	0.0	0.0	0.0	0.0	0.0
OH-	0.0	0.0	0.0	0.0	0.0
NACN(S)	346.3974	0.0	0.0	0.0	0.0
NAOH:(S)	0.0	0.0	0.0	0.0	0.0
NAOH(S)	0.0	0.0	0.0	0.0	0.0
CO3--	0.0	0.0	0.0	0.0	0.0
HCO3-	0.0	0.0	0.0	0.0	0.0
SODIU-01	0.0	0.0	0.0	0.0	0.0
SODIU-02	0.0	0.0	0.0	0.0	0.0
AMMON-01	0.0	0.0	0.0	0.0	0.0
DIAMM-01	0.0	0.0	0.0	0.0	0.0

NH4+	0.0	0.0	0.0	0.0	0.0
H2PO4-01	0.0	0.0	0.0	0.0	0.0
HPO4--01	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	346.3974	0.0	0.0	0.0	0.0
LB/HR	1.6976+04	0.0	0.0	0.0	0.0
CUFT/HR	166.4626	0.0	0.0	0.0	0.0
STATE VARIABLES:					
TEMP F	140.0970	MISSING	MISSING	MISSING	MISSING
PRES PSIA	14.6959	MISSING	11.6959	29.3919	26.3919
VFRAC	0.0	MISSING	MISSING	MISSING	MISSING
LFRAC	0.0	MISSING	MISSING	MISSING	MISSING
SFRAC	1.0000	MISSING	MISSING	MISSING	MISSING
ENTHALPY:					
BTU/LBMOL	-3.6553+04	MISSING	MISSING	MISSING	MISSING
BTU/LB	-745.8739	MISSING	MISSING	MISSING	MISSING
BTU/HR	-1.2662+07	MISSING	MISSING	MISSING	MISSING
ENTROPY:					
BTU/LBMOL-R	-6.9918	MISSING	MISSING	MISSING	MISSING
BTU/LB-R	-0.1427	MISSING	MISSING	MISSING	MISSING
DENSITY:					
LBMOL/CUFT	2.0809	MISSING	MISSING	MISSING	MISSING
LB/CUFT	101.9813	MISSING	MISSING	MISSING	MISSING
AVG MW	49.0075	MISSING	MISSING	MISSING	MISSING

NA2CO3 VAP

STREAM ID	NA2CO3	VAP
FROM :	E-103	SEP-102
TO :	----	----
CLASS:	MIXCISLD	MIXCISLD
TOTAL STREAM:		
LB/HR	422.7048	471.7892
BTU/HR	0.0	-3.1904+06
SUBSTREAM: MIXED		
PHASE:	LIQUID	LIQUID
COMPONENTS: LBMOL/HR		
CH4	0.0	0.0
NH3	0.0	0.0
CO2	0.0	0.0
HCN	0.0	0.0
CO	0.0	0.0
H2	0.0	0.0
O2	0.0	0.0
N2	0.0	0.0
H2O	0.0	26.1883
NAOH	0.0	0.0
H3O+	0.0	1.4540-07
NA+	7.9764	0.0
CN-	0.0	0.0
OH-	0.0	1.4540-07
NACN(S)	0.0	0.0
NAOH:(S)	0.0	0.0
NAOH(S)	0.0	0.0
CO3--	3.9874	0.0
HCO3-	7.5772-04	0.0
SODIU-01	0.0	0.0
SODIU-02	0.0	0.0
AMMON-01	0.0	0.0
DIAMM-01	0.0	0.0
NH4+	0.0	0.0
H2PO4-01	0.0	0.0
HPO4--01	0.0	0.0

```
TOTAL FLOW:
  LBMOL/HR                 11.9646    26.1883
  LB/HR                   422.7048   471.7892
  CUFT/HR                6771.0808     7.6868
STATE VARIABLES:
  TEMP   F                187.1619   140.0970
  PRES   PSIA              14.6959    14.6959
  VFRAC                     0.0        0.0
  LFRAC                     1.0000     1.0000
  SFRAC                     0.0        0.0
ENTHALPY:
  BTU/LBMOL                MISSING -1.2183+05
  BTU/LB                   MISSING -6762.3533
  BTU/HR                   MISSING -3.1904+06
ENTROPY:
  BTU/LBMOL-R              MISSING   -36.9719
  BTU/LB-R                 MISSING    -2.0523
DENSITY:
  LBMOL/CUFT               MISSING     3.4069
  LB/CUFT                  MISSING    61.3767
AVG MW                     35.3297    18.0153

1-5
---

STREAM ID                  1-5
FROM :                     ----
TO   :                     MIX1
CLASS:                     MIXCISLD
TOTAL STREAM:
  LB/HR                  1.2300+05
  BTU/HR                -3.1973+07
SUBSTREAM: MIXED
PHASE:                     VAPOR
COMPONENTS: LBMOL/HR
  CH4                     590.8389
  NH3                     496.0401
  CO2                       0.0
  HCN                       0.0
  CO                        0.0
  H2                        0.0
  O2                      767.2087
  N2                     2854.9863
  H2O                      30.5120
  NAOH                      0.0
  H3O+                      0.0
  NA+                       0.0
  CN-                       0.0
  OH-                       0.0
  NACN(S)                   0.0
  NAOH:(S)                  0.0
  NAOH(S)                   0.0
  CO3--                     0.0
  HCO3-                     0.0
  SODIU-01                  0.0
  SODIU-02                  0.0
  AMMON-01                  0.0
  DIAMM-01                  0.0
  NH4+                      0.0
  H2PO4-01                  0.0
  HPO4--01                  0.0
TOTAL FLOW:
  LBMOL/HR               4739.5859
  LB/HR                  1.2300+05
```

CUFT/HR	1.8553+06
STATE VARIABLES:	
TEMP F	77.0000
PRES PSIA	14.6959
VFRAC	1.0000
LFRAC	0.0
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	-6746.0164
BTU/LB	-259.9371
BTU/HR	-3.1973+07
ENTROPY:	
BTU/LBMOL-R	-2.7123
BTU/LB-R	-0.1045
DENSITY:	
LBMOL/CUFT	2.5546-03
LB/CUFT	6.6299-02
AVG MW	25.9525

6
-

STREAM ID	6
FROM :	MIX1
TO :	E-100A
CLASS:	MIXCISLD
CONV. MAX. REL. ERR:	6.9289-05
TOTAL STREAM:	
LB/HR	1.2532+05
BTU/HR	-3.8167+07
SUBSTREAM: MIXED	
PHASE:	VAPOR
COMPONENTS: LBMOL/HR	
CH4	590.8389
NH3	586.0180
CO2	1.8930-04
HCN	5.3175-06
CO	7.2219-03
H2	3.7127-04
O2	767.2087
N2	2854.9874
H2O	73.8034
NAOH	0.0
H3O+	0.0
NA+	0.0
CN-	0.0
OH-	0.0
NACN(S)	0.0
NAOH:(S)	0.0
NAOH(S)	0.0
CO3--	0.0
HCO3-	0.0
SODIU-01	0.0
SODIU-02	0.0
AMMON-01	0.0
DIAMM-01	0.0
NH4+	0.0
H2PO4-01	0.0
HPO4--01	0.0
TOTAL FLOW:	
LBMOL/HR	4872.8642
LB/HR	1.2532+05
CUFT/HR	1.9153+06

```
STATE VARIABLES:
  TEMP   F               79.2778
  PRES   PSIA            14.6959
  VFRAC                   1.0000
  LFRAC                   0.0
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -7832.5269
  BTU/LB               -304.5633
  BTU/HR              -3.8167+07
ENTROPY:
  BTU/LBMOL-R            -2.9783
  BTU/LB-R               -0.1158
DENSITY:
  LBMOL/CUFT          2.5441-03
  LB/CUFT             6.5428-02
AVG MW                  25.7172

7
-

STREAM ID               7
FROM :                  E-100A
TO   :                  R-100
CLASS:                  MIXCISLD
TOTAL STREAM:
  LB/HR               1.2532+05
  BTU/HR             -2.6526+07
SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: LBMOL/HR
  CH4                  590.8389
  NH3                  586.0180
  CO2                 1.8930-04
  HCN                 5.3175-06
  CO                  7.2219-03
  H2                  3.7127-04
  O2                   767.2087
  N2                  2854.9874
  H2O                   73.8034
  NAOH                   0.0
  H3O+                   0.0
  NA+                    0.0
  CN-                    0.0
  OH-                    0.0
  NACN(S)                0.0
  NAOH:(S)               0.0
  NAOH(S)                0.0
  CO3--                  0.0
  HCO3-                  0.0
  SODIU-01               0.0
  SODIU-02               0.0
  AMMON-01               0.0
  DIAMM-01               0.0
  NH4+                   0.0
  H2PO4-01               0.0
  HPO4--01               0.0
TOTAL FLOW:
  LBMOL/HR            4872.8642
  LB/HR               1.2532+05
  CUFT/HR             3.8076+06
STATE VARIABLES:
  TEMP   F              392.0000
  PRES   PSIA            11.6959
```

VFRAC	1.0000
LFRAC	0.0
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	-5443.5390
BTU/LB	-211.6689
BTU/HR	-2.6526+07
ENTROPY:	
BTU/LBMOL-R	0.9613
BTU/LB-R	3.7380-02
DENSITY:	
LBMOL/CUFT	1.2798-03
LB/CUFT	3.2912-02
AVG MW	25.7172

8
-

STREAM ID	8
FROM :	R-100
TO :	E-101
CLASS:	MIXCISLD
TOTAL STREAM:	
LB/HR	1.2532+05
BTU/HR	-2.6435+07
SUBSTREAM: MIXED	
PHASE:	VAPOR
COMPONENTS: LBMOL/HR	
CH4	11.1643
NH3	105.4832
CO2	21.2704
HCN	351.6108
CO	206.8008
H2	620.3812
O2	100.5592
N2	2919.4494
H2O	1157.7684
NAOH	0.0
H3O+	0.0
NA+	0.0
CN-	0.0
OH-	0.0
NACN(S)	0.0
NAOH:(S)	0.0
NAOH(S)	0.0
CO3--	0.0
HCO3-	0.0
SODIU-01	0.0
SODIU-02	0.0
AMMON-01	0.0
DIAMM-01	0.0
NH4+	0.0
H2PO4-01	0.0
HPO4--01	0.0
TOTAL FLOW:	
LBMOL/HR	5494.4877
LB/HR	1.2532+05
CUFT/HR	5.0539+06
STATE VARIABLES:	
TEMP F	2058.8000
PRES PSIA	29.3919
VFRAC	1.0000
LFRAC	0.0
SFRAC	0.0

```
ENTHALPY:
  BTU/LBMOL             -4811.1235
  BTU/LB                 -210.9430
  BTU/HR                -2.6435+07
ENTROPY:
  BTU/LBMOL-R              12.4253
  BTU/LB-R                  0.5448
DENSITY:
  LBMOL/CUFT             1.0872-03
  LB/CUFT                2.4796-02
AVG MW                     22.8077

9
-

STREAM ID                  9
FROM :                     E-101
TO   :                     E100B
CLASS:                     MIXCISLD
TOTAL STREAM:
  LB/HR                  1.2532+05
  BTU/HR                -9.4917+07
SUBSTREAM: MIXED
PHASE:                     VAPOR
COMPONENTS: LBMOL/HR
  CH4                      11.1643
  NH3                     105.4832
  CO2                      21.2704
  HCN                     351.6108
  CO                      206.8008
  H2                      620.3812
  O2                      100.5592
  N2                     2919.4494
  H2O                    1157.7684
  NAOH                      0.0
  H3O+                      0.0
  NA+                       0.0
  CN-                       0.0
  OH-                       0.0
  NACN(S)                   0.0
  NAOH:(S)                  0.0
  NAOH(S)                   0.0
  CO3--                     0.0
  HCO3-                     0.0
  SODIU-01                  0.0
  SODIU-02                  0.0
  AMMON-01                  0.0
  DIAMM-01                  0.0
  NH4+                      0.0
  H2PO4-01                  0.0
  HPO4--01                  0.0
TOTAL FLOW:
  LBMOL/HR               5494.4877
  LB/HR                  1.2532+05
  CUFT/HR                2.3688+06
STATE VARIABLES:
  TEMP   F                600.8000
  PRES   PSIA              26.3919
  VFRAC                     1.0000
  LFRAC                     0.0
  SFRAC                     0.0
ENTHALPY:
  BTU/LBMOL             -1.7275+04
  BTU/LB                 -757.4163
```

BTU/HR	-9.4917+07
ENTROPY:	
BTU/LBMOL-R	5.3299
BTU/LB-R	0.2337
DENSITY:	
LBMOL/CUFT	2.3196-03
LB/CUFT	5.2904-02
AVG MW	22.8077

10
--

STREAM ID	10
FROM :	E100B
TO :	E-102
CLASS:	MIXCISLD
TOTAL STREAM:	
LB/HR	1.2532+05
BTU/HR	-1.0656+08
SUBSTREAM: MIXED	
PHASE:	VAPOR
COMPONENTS: LBMOL/HR	
CH4	11.1643
NH3	105.4832
CO2	21.2704
HCN	351.6108
CO	206.8008
H2	620.3812
O2	100.5592
N2	2919.4494
H2O	1157.7684
NAOH	0.0
H3O+	0.0
NA+	0.0
CN-	0.0
OH-	0.0
NACN(S)	0.0
NAOH:(S)	0.0
NAOH(S)	0.0
CO3--	0.0
HCO3-	0.0
SODIU-01	0.0
SODIU-02	0.0
AMMON-01	0.0
DIAMM-01	0.0
NH4+	0.0
H2PO4-01	0.0
HPO4--01	0.0
TOTAL FLOW:	
LBMOL/HR	5494.4877
LB/HR	1.2532+05
CUFT/HR	1.9734+06
STATE VARIABLES:	
TEMP F	324.0483
PRES PSIA	23.3919
VFRAC	1.0000
LFRAC	0.0
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	-1.9394+04
BTU/LB	-850.3107
BTU/HR	-1.0656+08
ENTROPY:	
BTU/LBMOL-R	3.2563

BTU/LB-R	0.1428
DENSITY:	
LBMOL/CUFT	2.7843-03
LB/CUFT	6.3503-02
AVG MW	22.8077

11
--

STREAM ID	11
FROM :	E-102
TO :	V-100
CLASS:	MIXCISLD
TOTAL STREAM:	
LB/HR	1.2532+05
BTU/HR	-1.1334+08
SUBSTREAM: MIXED	
PHASE:	VAPOR
COMPONENTS: LBMOL/HR	
CH4	11.1643
NH3	105.4832
CO2	21.2704
HCN	351.6108
CO	206.8008
H2	620.3812
O2	100.5592
N2	2919.4494
H2O	1157.7684
NAOH	0.0
H3O+	0.0
NA+	0.0
CN-	0.0
OH-	0.0
NACN(S)	0.0
NAOH:(S)	0.0
NAOH(S)	0.0
CO3--	0.0
HCO3-	0.0
SODIU-01	0.0
SODIU-02	0.0
AMMON-01	0.0
DIAMM-01	0.0
NH4+	0.0
H2PO4-01	0.0
HPO4--01	0.0
TOTAL FLOW:	
LBMOL/HR	5494.4877
LB/HR	1.2532+05
CUFT/HR	2.4742+06
STATE VARIABLES:	
TEMP F	158.0000
PRES PSIA	14.6959
VFRAC	1.0000
LFRAC	0.0
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	-2.0629+04
BTU/LB	-904.4625
BTU/HR	-1.1334+08
ENTROPY:	
BTU/LBMOL-R	2.4078
BTU/LB-R	0.1056
DENSITY:	
LBMOL/CUFT	2.2207-03

```
  LB/CUFT              5.0650-02
AVG MW                   22.8077

12
--

STREAM ID                12
FROM :                   V-100
TO   :                   V-101
CLASS:                   MIXCISLD
TOTAL STREAM:
  LB/HR                1.2107+05
  BTU/HR              -1.6181+08
SUBSTREAM: MIXED
PHASE:                   VAPOR
COMPONENTS: LBMOL/HR
  CH4                    11.1643
  NH3                   105.2297
  CO2                    16.2848
  HCN                  3.2023-03
  CO                    206.7907
  H2                    620.3805
  O2                    100.5591
  N2                   2919.4473
  H2O                  1462.0003
  NAOH                    0.0
  H3O+                    0.0
  NA+                     0.0
  CN-                     0.0
  OH-                     0.0
  NACN(S)                 0.0
  NAOH:(S)                0.0
  NAOH(S)                 0.0
  CO3--                   0.0
  HCO3-                   0.0
  SODIU-01                0.0
  SODIU-02                0.0
  AMMON-01                0.0
  DIAMM-01                0.0
  NH4+                    0.0
  H2PO4-01                0.0
  HPO4--01                0.0
TOTAL FLOW:
  LBMOL/HR             5441.8598
  LB/HR                1.2107+05
  CUFT/HR              2.6640+06
STATE VARIABLES:
  TEMP   F              211.4760
  PRES   PSIA            14.6959
  VFRAC                   1.0000
  LFRAC                   0.0
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -2.9734+04
  BTU/LB              -1336.4816
  BTU/HR              -1.6181+08
ENTROPY:
  BTU/LBMOL-R             1.5597
  BTU/LB-R             7.0107-02
DENSITY:
  LBMOL/CUFT           2.0427-03
  LB/CUFT              4.5447-02
AVG MW                   22.2481
```

13
--

```
STREAM ID                  13
FROM :                     V-101
TO   :                     ----
CLASS:                     MIXCISLD
TOTAL STREAM:
  LB/HR                  1.2511+05
  BTU/HR                -1.9437+08
SUBSTREAM: MIXED
PHASE:                     VAPOR
COMPONENTS: LBMOL/HR
  CH4                      11.1643
  NH3                      14.2103
  CO2                      16.2846
  HCN                    3.1964-03
  CO                      206.7835
  H2                      620.3801
  O2                      100.5590
  N2                     2919.4462
  H2O                    1772.4109
  NAOH                        0.0
  H3O+                        0.0
  NA+                         0.0
  CN-                         0.0
  OH-                         0.0
  NACN(S)                     0.0
  NAOH:(S)                    0.0
  NAOH(S)                     0.0
  CO3--                       0.0
  HCO3-                       0.0
  SODIU-01                    0.0
  SODIU-02                    0.0
  AMMON-01                    0.0
  DIAMM-01                    0.0
  NH4+                        0.0
  H2PO4-01                    0.0
  HPO4--01                    0.0
TOTAL FLOW:
  LBMOL/HR               5661.2421
  LB/HR                  1.2511+05
  CUFT/HR                2.5441+06
STATE VARIABLES:
  TEMP   F                156.8182
  PRES   PSIA              14.6959
  VFRAC                     1.0000
  LFRAC                     0.0
  SFRAC                     0.0
ENTHALPY:
  BTU/LBMOL             -3.4333+04
  BTU/LB                -1553.5276
  BTU/HR                -1.9437+08
ENTROPY:
  BTU/LBMOL-R               0.7266
  BTU/LB-R               3.2876-02
DENSITY:
  LBMOL/CUFT             2.2252-03
  LB/CUFT                4.9177-02
AVG MW                     22.0999
```

14-15

```
STREAM ID                 14-15
FROM :                    V-101
TO   :                    V-102
CLASS:                    MIXCISLD
TOTAL STREAM:
  LB/HR                 2.1347+04
  BTU/HR               -1.1888+08
SUBSTREAM: MIXED
PHASE:                    LIQUID
COMPONENTS: LBMOL/HR
  CH4                   7.6051-06
  NH3                      0.1165
  CO2                   1.8929-04
  HCN                   5.8667-06
  CO                    7.2217-03
  H2                    3.7125-04
  O2                    6.8535-05
  N2                    1.1342-03
  H2O                    395.0686
  NAOH                     0.0
  H3O+                  1.6593-07
  NA+                      0.0
  CN-                   3.3657-08
  OH-                   1.3227-07
  NACN(S)                  0.0
  NAOH:(S)                 0.0
  NAOH(S)                  0.0
  CO3--                    0.0
  HCO3-                    0.0
  SODIU-01                 0.0
  SODIU-02                 0.0
  AMMON-01                 0.0
  DIAMM-01                 0.0
  NH4+                   201.1341
  H2PO4-01                19.3282
  HPO4--01                90.9029
TOTAL FLOW:
  LBMOL/HR               706.5593
  LB/HR                 2.1347+04
  CUFT/HR                204.2474
STATE VARIABLES:
  TEMP   F             -5.3989-02
  PRES   PSIA             14.6959
  VFRAC                    0.0
  LFRAC                    1.0000
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL            -1.6826+05
  BTU/LB               -5569.0833
  BTU/HR               -1.1888+08
ENTROPY:
  BTU/LBMOL-R            -50.9124
  BTU/LB-R                -1.6851
DENSITY:
  LBMOL/CUFT               3.4593
  LB/CUFT                104.5156
AVG MW                    30.2127

16
--

STREAM ID                 16
FROM :                    V-102
TO   :                    ----
```

```
CLASS:                  MIXCISLD
TOTAL STREAM:
  LB/HR               2.3003+04
  BTU/HR             -1.3504+08
SUBSTREAM: MIXED
PHASE:                  MIXED
COMPONENTS: LBMOL/HR
  CH4                    0.0
  NH3                    1.0416
  CO2                 9.8460-11
  HCN                 3.4574-07
  CO                  3.0917-08
  H2                     0.0
  O2                     0.0
  N2                     0.0
  H2O                  572.0466
  NAOH                   0.0
  H3O+                4.0637-04
  NA+                    0.0
  CN-                 2.3688-07
  OH-                 4.0614-04
  NACN(S)                0.0
  NAOH:(S)               0.0
  NAOH(S)                0.0
  CO3--                  0.0
  HCO3-                  0.0
  SODIU-01               0.0
  SODIU-02               0.0
  AMMON-01               0.0
  DIAMM-01               0.0
  NH4+                 110.2311
  H2PO4-01             110.2311
  HPO4--01               0.0
TOTAL FLOW:
  LBMOL/HR             793.5512
  LB/HR               2.3003+04
  CUFT/HR              276.3248
STATE VARIABLES:
  TEMP   F             190.0521
  PRES   PSIA           14.6959
  VFRAC               2.2242-05
  LFRAC                  1.0000
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -1.7017+05
  BTU/LB             -5870.7123
  BTU/HR             -1.3504+08
ENTROPY:
  BTU/LBMOL-R          -44.6361
  BTU/LB-R              -1.5399
DENSITY:
  LBMOL/CUFT             2.8718
  LB/CUFT               83.2453
AVG MW                  28.9871

18
--

STREAM ID               18
FROM :                  ----
TO   :                  V-101
CLASS:                  MIXCISLD
TOTAL STREAM:
  LB/HR               2.5389+04
```

```
  BTU/HR               -1.5144+08
SUBSTREAM: MIXED
PHASE:                    LIQUID
COMPONENTS: LBMOL/HR
  CH4                      0.0
  NH3                      0.0
  CO2                      0.0
  HCN                      0.0
  CO                       0.0
  H2                       0.0
  O2                       0.0
  N2                       0.0
  H2O                    705.4789
  NAOH                     0.0
  H3O+                  1.6741-04
  NA+                      0.0
  CN-                      0.0
  OH-                   1.6741-04
  NACN(S)                  0.0
  NAOH:(S)                 0.0
  NAOH(S)                  0.0
  CO3--                    0.0
  HCO3-                    0.0
  SODIU-01                 0.0
  SODIU-02                 0.0
  AMMON-01                 0.0
  DIAMM-01                 0.0
  NH4+                   110.2311
  H2PO4-01               110.2311
  HPO4--01                 0.0
TOTAL FLOW:
  LBMOL/HR               925.9415
  LB/HR                 2.5389+04
  CUFT/HR                303.0923
STATE VARIABLES:
  TEMP   F               158.0000
  PRES   PSIA             14.6959
  VFRAC                    0.0
  LFRAC                    1.0000
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL            -1.6355+05
  BTU/LB               -5964.8440
  BTU/HR               -1.5144+08
ENTROPY:
  BTU/LBMOL-R            -43.9290
  BTU/LB-R                -1.6021
DENSITY:
  LBMOL/CUFT               3.0550
  LB/CUFT                 83.7660
AVG MW                    27.4195

19
--

STREAM ID                 19
FROM :                    ----
TO   :                    V-102
CLASS:                    MIXCISLD
TOTAL STREAM:
  LB/HR                 3968.3207
  BTU/HR               -2.2354+07
SUBSTREAM: MIXED
PHASE:                    VAPOR
```

```
COMPONENTS: LBMOL/HR
  CH4                     0.0
  NH3                     0.0
  CO2                     0.0
  HCN                     0.0
  CO                      0.0
  H2                      0.0
  O2                      0.0
  N2                      0.0
  H2O                   220.2753
  NAOH                    0.0
  H3O+                    0.0
  NA+                     0.0
  CN-                     0.0
  OH-                     0.0
  NACN(S)                 0.0
  NAOH:(S)                0.0
  NAOH(S)                 0.0
  CO3--                   0.0
  HCO3-                   0.0
  SODIU-01                0.0
  SODIU-02                0.0
  AMMON-01                0.0
  DIAMM-01                0.0
  NH4+                    0.0
  H2PO4-01                0.0
  HPO4--01                0.0
TOTAL FLOW:
  LBMOL/HR              220.2753
  LB/HR                3968.3207
  CUFT/HR              1.3648+05
STATE VARIABLES:
  TEMP   F              392.0000
  PRES   PSIA            14.6959
  VFRAC                   1.0000
  LFRAC                   0.0
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -1.0148+05
  BTU/LB              -5632.9893
  BTU/HR              -2.2354+07
ENTROPY:
  BTU/LBMOL-R            -6.8383
  BTU/LB-R               -0.3796
DENSITY:
  LBMOL/CUFT           1.6140-03
  LB/CUFT              2.9077-02
AVG MW                   18.0153

20
--

STREAM ID                20
FROM :                   V-102
TO   :                   MIX1
CLASS:                   MIXCISLD
TOTAL STREAM:
  LB/HR                2312.6169
  BTU/HR              -6.1940+06
SUBSTREAM: MIXED
PHASE:                   VAPOR
COMPONENTS: LBMOL/HR
  CH4                  7.6051-06
  NH3                    89.9778
```

```
    CO2                       1.8929-04
    HCN                       5.3177-06
    CO                        7.2217-03
    H2                        3.7125-04
    O2                        6.8535-05
    N2                        1.1342-03
    H2O                         43.2965
    NAOH                         0.0
    H3O+                         0.0
    NA+                          0.0
    CN-                          0.0
    OH-                          0.0
    NACN(S)                      0.0
    NAOH:(S)                     0.0
    NAOH(S)                      0.0
    CO3--                        0.0
    HCO3-                        0.0
    SODIU-01                     0.0
    SODIU-02                     0.0
    AMMON-01                     0.0
    DIAMM-01                     0.0
    NH4+                         0.0
    H2PO4-01                     0.0
    HPO4--01                     0.0
  TOTAL FLOW:
    LBMOL/HR                   133.2833
    LB/HR                     2312.6169
    CUFT/HR                   5.8953+04
  STATE VARIABLES:
    TEMP   F                   149.9129
    PRES   PSIA                 14.6959
    VFRAC                        1.0000
    LFRAC                        0.0
    SFRAC                        0.0
  ENTHALPY:
    BTU/LBMOL                -4.6473+04
    BTU/LB                   -2678.3688
    BTU/HR                   -6.1940+06
  ENTROPY:
    BTU/LBMOL-R                -17.1172
    BTU/LB-R                    -0.9865
  DENSITY:
    LBMOL/CUFT                2.2609-03
    LB/CUFT                   3.9228-02
  AVG MW                        17.3511

  21
  --

  STREAM ID                     21
  FROM :                        ----
  TO   :                        V-100
  CLASS:                        MIXCISLD
  TOTAL STREAM:
    LB/HR                     2.9432+04
    BTU/HR                   -1.7068+08
  SUBSTREAM: MIXED
  PHASE:                        LIQUID
  COMPONENTS: LBMOL/HR
    CH4                          0.0
    NH3                          0.0
    CO2                          0.0
    HCN                          0.0
    CO                           0.0
```

```
   H2                          0.0
   O2                          0.0
   N2                          0.0
   H2O                       816.8541
   NAOH                        0.0
   H3O+                    1.4041-15
   NA+                       367.9230
   CN-                         0.0
   OH-                       367.9230
   NACN(S)                     0.0
   NAOH:(S)                    0.0
   NAOH(S)                     0.0
   CO3--                       0.0
   HCO3-                       0.0
   SODIU-01                    0.0
   SODIU-02                    0.0
   AMMON-01                    0.0
   DIAMM-01                    0.0
   NH4+                        0.0
   H2PO4-01                    0.0
   HPO4--01                    0.0
 TOTAL FLOW:
   LBMOL/HR                1552.7001
   LB/HR                   2.9432+04
   CUFT/HR                  315.0386
 STATE VARIABLES:
   TEMP   F                 158.0000
   PRES   PSIA               14.6959
   VFRAC                       0.0
   LFRAC                       1.0000
   SFRAC                       0.0
 ENTHALPY:
   BTU/LBMOL              -1.0992+05
   BTU/LB                 -5799.0469
   BTU/HR                 -1.7068+08
 ENTROPY:
   BTU/LBMOL-R              -28.1553
   BTU/LB-R                  -1.4854
 DENSITY:
   LBMOL/CUFT                 4.9286
   LB/CUFT                   93.4226
 AVG MW                      18.9552

 22
 --

 STREAM ID                   22
 FROM :                      V-100
 TO   :                      E-103
 CLASS:                      MIXCISLD
 TOTAL STREAM:
   LB/HR                   3.3677+04
   BTU/HR                 -1.2221+08
 SUBSTREAM: MIXED
 PHASE:                      LIQUID
 COMPONENTS: LBMOL/HR
   CH4                     1.3458-05
   NH3                        0.2535
   CO2                     3.3919-04
   HCN                     4.0140-03
   CO                      1.0126-02
   H2                      7.0812-04
   O2                      1.2311-04
   N2                      2.1135-03
```

```
    H2O                     869.2101
    NAOH                      0.0
    H3O+                  7.9413-12
    NA+                     367.9230
    CN-                     351.6036
    OH-                       6.3499
    NACN(S)                   0.0
    NAOH:(S)                  0.0
    NAOH(S)                   0.0
    CO3--                     4.9843
    HCO3-                 9.4715-04
    SODIU-01                  0.0
    SODIU-02                  0.0
    AMMON-01                  0.0
    DIAMM-01                  0.0
    NH4+                      0.0
    H2PO4-01                  0.0
    HPO4--01                  0.0
  TOTAL FLOW:
    LBMOL/HR              1600.3428
    LB/HR                 3.3677+04
    CUFT/HR                842.1076
  STATE VARIABLES:
    TEMP   F               187.1619
    PRES   PSIA             14.6959
    VFRAC                     0.0
    LFRAC                     1.0000
    SFRAC                     0.0
  ENTHALPY:
    BTU/LBMOL            -7.6365+04
    BTU/LB               -3628.8648
    BTU/HR               -1.2221+08
  ENTROPY:
    BTU/LBMOL-R             -20.6638
    BTU/LB-R                 -0.9819
  DENSITY:
    LBMOL/CUFT                1.9004
    LB/CUFT                  39.9918
  AVG MW                     21.0439

  22-23
  -----

  STREAM ID                  22-23
  FROM :                     E-103
  TO   :                     E-103HX
  CLASS:                     MIXCISLD
  TOTAL STREAM:
    LB/HR                 3.3255+04
    BTU/HR               -1.2024+08
  SUBSTREAM: MIXED
  PHASE:                     MIXED
  COMPONENTS: LBMOL/HR
    CH4                   1.3458-05
    NH3                       0.2535
    CO2                   3.3919-04
    HCN                   4.0983-03
    CO                    1.0126-02
    H2                    7.0812-04
    O2                    1.2311-04
    N2                    2.1135-03
    H2O                     869.2101
    NAOH                      0.0
    H3O+                  8.1295-12
```

```
   NA+                     359.9466
   CN-                     351.6035
   OH-                       6.3499
   NACN(S)                   0.0
   NAOH:(S)                  0.0
   NAOH(S)                   0.0
   CO3--                     0.9969
   HCO3-                   1.8943-04
   SODIU-01                  0.0
   SODIU-02                  0.0
   AMMON-01                  0.0
   DIAMM-01                  0.0
   NH4+                      0.0
   H2PO4-01                  0.0
   HPO4--01                  0.0
 TOTAL FLOW:
   LBMOL/HR               1588.3782
   LB/HR                  3.3255+04
   CUFT/HR                 840.1798
 STATE VARIABLES:
   TEMP   F                187.1619
   PRES   PSIA              14.6959
   VFRAC                  2.3432-08
   LFRAC                     1.0000
   SFRAC                     0.0
 ENTHALPY:
   BTU/LBMOL             -7.5701+04
   BTU/LB                -3615.7691
   BTU/HR                -1.2024+08
 ENTROPY:
   BTU/LBMOL-R             -20.6289
   BTU/LB-R                 -0.9853
 DENSITY:
   LBMOL/CUFT                1.8905
   LB/CUFT                  39.5805
 AVG MW                     20.9363

 23
 --

 STREAM ID                  23
 FROM :                     E-103HX
 TO   :                     MIX2
 CLASS:                     MIXCISLD
 TOTAL STREAM:
   LB/HR                  3.3255+04
   BTU/HR                -1.2011+08
 SUBSTREAM: MIXED
 PHASE:                     MIXED
 COMPONENTS: LBMOL/HR
   CH4                    1.3458-05
   NH3                       0.2535
   CO2                    3.3919-04
   HCN                    4.5851-03
   CO                     1.0126-02
   H2                     7.0812-04
   O2                     1.2311-04
   N2                     2.1135-03
   H2O                     869.2096
   NAOH                      0.0
   H3O+                   1.0687-11
   NA+                     359.9466
   CN-                     351.6030
   OH-                       6.3504
```

```
  NACN(S)                0.0
  NAOH:(S)               0.0
  NAOH(S)                0.0
  CO3--                  0.9969
  HCO3-               1.8943-04
  SODIU-01               0.0
  SODIU-02               0.0
  AMMON-01               0.0
  DIAMM-01               0.0
  NH4+                   0.0
  H2PO4-01               0.0
  HPO4--01               0.0
TOTAL FLOW:
  LBMOL/HR            1588.3782
  LB/HR               3.3255+04
  CUFT/HR              843.3449
STATE VARIABLES:
  TEMP   F             196.1619
  PRES   PSIA           14.6959
  VFRAC               3.1836-07
  LFRAC                  1.0000
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -7.5616+04
  BTU/LB             -3611.7327
  BTU/HR             -1.2011+08
ENTROPY:
  BTU/LBMOL-R          -20.4992
  BTU/LB-R              -0.9791
DENSITY:
  LBMOL/CUFT             1.8834
  LB/CUFT               39.4319
AVG MW                  20.9363

24
--

STREAM ID               24
FROM :                  MIX2
TO   :                  SEP-100
CLASS:                  MIXCISLD
TOTAL STREAM:
  LB/HR               1.0173+05
  BTU/HR             -4.5090+08
SUBSTREAM: MIXED
PHASE:                  LIQUID
COMPONENTS: LBMOL/HR
  CH4                 1.3458-05
  NH3                    0.2540
  CO2                 3.3919-04
  HCN                 1.4913-04
  CO                  1.0126-02
  H2                  7.0812-04
  O2                  1.2311-04
  N2                  2.1135-03
  H2O                 2791.9291
  NAOH                   0.0
  H3O+                1.1926-13
  NA+                 1125.9079
  CN-                  693.7436
  OH-                  423.6449
  NACN(S)                0.0
  NAOH:(S)               0.0
  NAOH(S)                0.0
```

```
  CO3--                    4.8801
  HCO3-                 1.2627-02
  SODIU-01                 0.0
  SODIU-02                 0.0
  AMMON-01                 0.0
  DIAMM-01                 0.0
  NH4+                     0.0
  H2PO4-01                 0.0
  HPO4--01                 0.0
TOTAL FLOW:
  LBMOL/HR              5040.3859
  LB/HR                 1.0173+05
  CUFT/HR               2036.2787
STATE VARIABLES:
  TEMP   F               156.6218
  PRES   PSIA             14.6959
  VFRAC                    0.0
  LFRAC                    1.0000
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL            -8.9458+04
  BTU/LB               -4432.1465
  BTU/HR               -4.5090+08
ENTROPY:
  BTU/LBMOL-R            -23.8765
  BTU/LB-R                -1.1829
DENSITY:
  LBMOL/CUFT               2.4753
  LB/CUFT                 49.9611
AVG MW                    20.1839

25
--

STREAM ID                 25
FROM :                    SEP-100
TO   :                    P-101
CLASS:                    MIXCISLD
TOTAL STREAM:
  LB/HR                 8.6599+04
  BTU/HR               -3.4896+08
SUBSTREAM: MIXED
PHASE:                    LIQUID
COMPONENTS: LBMOL/HR
  CH4                   1.2339-11
  NH3                   4.8699-04
  CO2                   5.7467-09
  HCN                   3.1818-05
  CO                    5.4285-07
  H2                    5.2810-10
  O2                    1.1095-10
  N2                    1.0574-09
  H2O                   1952.0236
  NAOH                     0.0
  H3O+                  1.6806-14
  NA+                    777.6379
  CN-                    347.3360
  OH-                    423.6551
  NACN(S)                  0.0
  NAOH:(S)                 0.0
  NAOH(S)                  0.0
  CO3--                    3.9438
  HCO3-                 1.2627-02
  SODIU-01                 0.0
```

```
    SODIU-02                  0.9363
    AMMON-01                  0.0
    DIAMM-01                  0.0
    NH4+                      0.0
    H2PO4-01                  0.0
    HPO4--01                  0.0
  TOTAL FLOW:
    LBMOL/HR               3505.5459
    LB/HR                  6.9623+04
    CUFT/HR                1217.3461
  STATE VARIABLES:
    TEMP   F                140.0000
    PRES   PSIA               0.9001
    VFRAC                     0.0
    LFRAC                     1.0000
    SFRAC                     0.0
  ENTHALPY:
    BTU/LBMOL             -9.5814+04
    BTU/LB                -4824.2890
    BTU/HR                -3.3588+08
  ENTROPY:
    BTU/LBMOL-R             -26.8566
    BTU/LB-R                 -1.3522
  DENSITY:
    LBMOL/CUFT                2.8797
    LB/CUFT                  57.1923
  AVG MW                     19.8608

  SUBSTREAM: CISOLID       STRUCTURE: CONVENTIONAL
  COMPONENTS: LBMOL/HR
    CH4                       0.0
    NH3                       0.0
    CO2                       0.0
    HCN                       0.0
    CO                        0.0
    H2                        0.0
    O2                        0.0
    N2                        0.0
    H2O                       0.0
    NAOH                      0.0
    H3O+                      0.0
    NA+                       0.0
    CN-                       0.0
    OH-                       0.0
    NACN(S)                 346.3974
    NAOH:(S)                  0.0
    NAOH(S)                   0.0
    CO3--                     0.0
    HCO3-                     0.0
    SODIU-01                  0.0
    SODIU-02                  0.0
    AMMON-01                  0.0
    DIAMM-01                  0.0
    NH4+                      0.0
    H2PO4-01                  0.0
    HPO4--01                  0.0
  TOTAL FLOW:
    LBMOL/HR                346.3974
    LB/HR                  1.6976+04
    CUFT/HR                 166.6399
  STATE VARIABLES:
    TEMP   F                140.0000
    PRES   PSIA               0.9001
    VFRAC                     0.0
```

```
  LFRAC                    0.0
  SFRAC                    1.0000
ENTHALPY:
  BTU/LBMOL            -3.7761+04
  BTU/LB                -770.5065
  BTU/HR               -1.3080+07
ENTROPY:
  BTU/LBMOL-R             -7.1505
  BTU/LB-R                -0.1459
DENSITY:
  LBMOL/CUFT               2.0787
  LB/CUFT                101.8728
AVG MW                    49.0075

26
--

STREAM ID                 26
FROM :                    SEP-100
TO   :                    ----
CLASS:                    MIXCISLD
TOTAL STREAM:
  LB/HR                 1.5136+04
  BTU/HR               -8.6962+07
SUBSTREAM: MIXED
PHASE:                    VAPOR
COMPONENTS: LBMOL/HR
  CH4                   1.3458-05
  NH3                      0.2535
  CO2                   3.3919-04
  HCN                   1.0354-02
  CO                    1.0126-02
  H2                    7.0812-04
  O2                    1.2311-04
  N2                    2.1135-03
  H2O                    839.8953
  NAOH                     0.0
  H3O+                     0.0
  NA+                      0.0
  CN-                      0.0
  OH-                      0.0
  NACN(S)                  0.0
  NAOH:(S)                 0.0
  NAOH(S)                  0.0
  CO3--                    0.0
  HCO3-                    0.0
  SODIU-01                 0.0
  SODIU-02                 0.0
  AMMON-01                 0.0
  DIAMM-01                 0.0
  NH4+                     0.0
  H2PO4-01                 0.0
  HPO4--01                 0.0
TOTAL FLOW:
  LBMOL/HR               840.1726
  LB/HR                 1.5136+04
  CUFT/HR               6.0033+06
STATE VARIABLES:
  TEMP   F               140.0000
  PRES   PSIA              0.9001
  VFRAC                    1.0000
  LFRAC                    0.0
  SFRAC                    0.0
ENTHALPY:
```

```
  BTU/LBMOL           -1.0351+05
  BTU/LB              -5745.4326
  BTU/HR              -8.6962+07
ENTROPY:
  BTU/LBMOL-R            -4.1566
  BTU/LB-R               -0.2307
DENSITY:
  LBMOL/CUFT           1.3995-04
  LB/CUFT              2.5213-03
AVG MW                   18.0152

28
--

STREAM ID                28
FROM :                   P-101
TO   :                   SEP-101
CLASS:                   MIXCISLD
TOTAL STREAM:
  LB/HR                8.6599+04
  BTU/HR              -3.4896+08
SUBSTREAM: MIXED
PHASE:                   MIXED
COMPONENTS: LBMOL/HR
  CH4                  1.3153-11
  NH3                  4.8699-04
  CO2                  5.7467-09
  HCN                  3.1858-05
  CO                   5.4285-07
  H2                   5.2810-10
  O2                   1.1095-10
  N2                   1.0574-09
  H2O                  1952.0236
  NAOH                    0.0
  H3O+                 1.6866-14
  NA+                   777.6351
  CN-                   347.3360
  OH-                   423.6551
  NACN(S)                 0.0
  NAOH:(S)                0.0
  NAOH(S)                 0.0
  CO3--                   3.9424
  HCO3-                1.2627-02
  SODIU-01                0.0
  SODIU-02                0.9377
  AMMON-01                0.0
  DIAMM-01                0.0
  NH4+                    0.0
  H2PO4-01                0.0
  HPO4--01                0.0
TOTAL FLOW:
  LBMOL/HR             3505.5430
  LB/HR                6.9623+04
  CUFT/HR              1217.5366
STATE VARIABLES:
  TEMP   F              140.0834
  PRES   PSIA            14.5038
  VFRAC                   0.0
  LFRAC                   0.9997
  SFRAC                2.6750-04
ENTHALPY:
  BTU/LBMOL           -9.5932+04
  BTU/LB              -4830.2187
  BTU/HR              -3.3629+08
```

```
ENTROPY:
  BTU/LBMOL-R          -25.5814
  BTU/LB-R              -1.2880
DENSITY:
  LBMOL/CUFT             2.8792
  LB/CUFT               57.1833
AVG MW                  19.8608

SUBSTREAM: CISOLID      STRUCTURE: CONVENTIONAL
COMPONENTS: LBMOL/HR
  CH4                    0.0
  NH3                    0.0
  CO2                    0.0
  HCN                    0.0
  CO                     0.0
  H2                     0.0
  O2                     0.0
  N2                     0.0
  H2O                    0.0
  NAOH                   0.0
  H3O+                   0.0
  NA+                    0.0
  CN-                    0.0
  OH-                    0.0
  NACN(S)              346.3974
  NAOH:(S)               0.0
  NAOH(S)                0.0
  CO3--                  0.0
  HCO3-                  0.0
  SODIU-01               0.0
  SODIU-02               0.0
  AMMON-01               0.0
  DIAMM-01               0.0
  NH4+                   0.0
  H2PO4-01               0.0
  HPO4--01               0.0
TOTAL FLOW:
  LBMOL/HR             346.3974
  LB/HR               1.6976+04
  CUFT/HR              166.4626
STATE VARIABLES:
  TEMP   F             140.0834
  PRES   PSIA           14.5038
  VFRAC                  0.0
  LFRAC                  0.0
  SFRAC                  1.0000
ENTHALPY:
  BTU/LBMOL          -3.6554+04
  BTU/LB              -745.8785
  BTU/HR             -1.2662+07
ENTROPY:
  BTU/LBMOL-R           -6.9922
  BTU/LB-R              -0.1427
DENSITY:
  LBMOL/CUFT             2.0809
  LB/CUFT              101.9813
AVG MW                  49.0075

29
--

STREAM ID               29
FROM :                  SEP-101
TO   :                  MIX2
```

```
CLASS:                    MIXCISLD

CONV. MAX. REL. ERR: -7.0967-05
TOTAL STREAM:
  LB/HR                 6.8480+04
  BTU/HR               -3.3080+08
SUBSTREAM: MIXED
PHASE:                    MIXED
COMPONENTS: LBMOL/HR
  CH4                   1.2950-11
  NH3                   4.7940-04
  CO2                   5.6572-09
  HCN                   3.1386-05
  CO                    5.3440-07
  H2                    5.1994-10
  O2                    1.0923-10
  N2                    1.0412-09
  H2O                   1922.7151
  NAOH                     0.0
  H3O+                  1.6622-14
  NA+                    765.9608
  CN-                    342.1361
  OH-                    417.2989
  NACN(S)                  0.0
  NAOH:(S)                 0.0
  NAOH(S)                  0.0
  CO3--                    3.8830
  HCO3-                 1.2438-02
  SODIU-01                 0.0
  SODIU-02              2.7142-04
  AMMON-01                 0.0
  DIAMM-01                 0.0
  NH4+                     0.0
  H2PO4-01                 0.0
  HPO4--01                 0.0
TOTAL FLOW:
  LBMOL/HR              3452.0071
  LB/HR                 6.8480+04
  CUFT/HR               1198.6506
STATE VARIABLES:
  TEMP   F               140.0970
  PRES   PSIA             14.6959
  VFRAC                    0.0
  LFRAC                    1.0000
  SFRAC                 1.5328-07
ENTHALPY:
  BTU/LBMOL            -9.5827+04
  BTU/LB               -4830.5510
  BTU/HR               -3.3080+08
ENTROPY:
  BTU/LBMOL-R            -25.5706
  BTU/LB-R                -1.2890
DENSITY:
  LBMOL/CUFT               2.8799
  LB/CUFT                 57.1310
AVG MW                    19.8378

30
--

STREAM ID                 30
FROM :                    SEP-101
TO   :                    SEP-102
CLASS:                    MIXCISLD
```

```
TOTAL STREAM:
  LB/HR                  1.8118+04
  BTU/HR                -1.8153+07
SUBSTREAM: MIXED
PHASE:                     MIXED
COMPONENTS: LBMOL/HR
  CH4                      0.0
  NH3                    7.3049-06
  CO2                    8.6200-11
  HCN                    4.7795-07
  CO                     8.1428-09
  H2                       0.0
  O2                       0.0
  N2                     1.5861-11
  H2O                     29.2804
  NAOH                     0.0
  H3O+                   2.5312-16
  NA+                     11.6645
  CN-                      5.2100
  OH-                      6.3548
  NACN(S)                  0.0
  NAOH:(S)                 0.0
  NAOH(S)                  0.0
  CO3--                  5.9128-02
  HCO3-                  1.8941-04
  SODIU-01                 0.0
  SODIU-02                 0.9378
  AMMON-01                 0.0
  DIAMM-01                 0.0
  NH4+                     0.0
  H2PO4-01                 0.0
  HPO4--01                 0.0
TOTAL FLOW:
  LBMOL/HR                53.5068
  LB/HR                  1142.2412
  CUFT/HR                 18.8823
STATE VARIABLES:
  TEMP   F               140.0970
  PRES   PSIA             14.6959
  VFRAC                    0.0
  LFRAC                    0.9825
  SFRAC                  1.7526-02
ENTHALPY:
  BTU/LBMOL             -1.0263+05
  BTU/LB                -4807.4212
  BTU/HR                -5.4912+06
ENTROPY:
  BTU/LBMOL-R            -26.2591
  BTU/LB-R                -1.2301
DENSITY:
  LBMOL/CUFT               2.8337
  LB/CUFT                 60.4926
AVG MW                    21.3476

SUBSTREAM: CISOLID        STRUCTURE: CONVENTIONAL
COMPONENTS: LBMOL/HR
  CH4                      0.0
  NH3                      0.0
  CO2                      0.0
  HCN                      0.0
  CO                       0.0
  H2                       0.0
  O2                       0.0
  N2                       0.0
```

```
    H2O                        0.0
    NAOH                       0.0
    H3O+                       0.0
    NA+                        0.0
    CN-                        0.0
    OH-                        0.0
    NACN(S)                  346.3974
    NAOH:(S)                   0.0
    NAOH(S)                    0.0
    CO3--                      0.0
    HCO3-                      0.0
    SODIU-01                   0.0
    SODIU-02                   0.0
    AMMON-01                   0.0
    DIAMM-01                   0.0
    NH4+                       0.0
    H2PO4-01                   0.0
    HPO4--01                   0.0
  TOTAL FLOW:
    LBMOL/HR                 346.3974
    LB/HR                  1.6976+04
    CUFT/HR                  166.4626
  STATE VARIABLES:
    TEMP   F                 140.0970
    PRES   PSIA               14.6959
    VFRAC                      0.0
    LFRAC                      0.0
    SFRAC                      1.0000
  ENTHALPY:
    BTU/LBMOL             -3.6553+04
    BTU/LB                 -745.8739
    BTU/HR                -1.2662+07
  ENTROPY:
    BTU/LBMOL-R               -6.9918
    BTU/LB-R                  -0.1427
  DENSITY:
    LBMOL/CUFT                 2.0809
    LB/CUFT                  101.9813
  AVG MW                      49.0075

  31
  --

  STREAM ID                   31
  FROM :                      ----
  TO   :                      E-105
  CLASS:                      MIXCISLD
  TOTAL STREAM:
    LB/HR                  2.2430+04
    BTU/HR                -1.1293+07
  SUBSTREAM: MIXED
  PHASE:                      VAPOR
  COMPONENTS: LBMOL/HR
    CH4                        0.0
    NH3                        0.0
    CO2                        0.0
    HCN                        0.0
    CO                         0.0
    H2                         0.0
    O2                       489.3412
    N2                       169.7923
    H2O                      111.8509
    NAOH                       0.0
    H3O+                       0.0
```

NA+	0.0
CN-	0.0
OH-	0.0
NACN(S)	0.0
NAOH:(S)	0.0
NAOH(S)	0.0
CO3--	0.0
HCO3-	0.0
SODIU-01	0.0
SODIU-02	0.0
AMMON-01	0.0
DIAMM-01	0.0
NH4+	0.0
H2PO4-01	0.0
HPO4--01	0.0
TOTAL FLOW:	
LBMOL/HR	770.9844
LB/HR	2.2430+04
CUFT/HR	2.7999+05
STATE VARIABLES:	
TEMP F	140.0000
PRES PSIA	17.6959
VFRAC	1.0000
LFRAC	0.0
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	-1.4647+04
BTU/LB	-503.4772
BTU/HR	-1.1293+07
ENTROPY:	
BTU/LBMOL-R	0.6739
BTU/LB-R	2.3164-02
DENSITY:	
LBMOL/CUFT	2.7536-03
LB/CUFT	8.0110-02
AVG MW	29.0925

32
--

STREAM ID	32
FROM :	E-105
TO :	P-102
CLASS:	MIXCISLD
TOTAL STREAM:	
LB/HR	2.1958+04
BTU/HR	-8.6765+06
SUBSTREAM: MIXED	
PHASE:	VAPOR
COMPONENTS: LBMOL/HR	
CH4	0.0
NH3	0.0
CO2	0.0
HCN	0.0
CO	0.0
H2	0.0
O2	489.3412
N2	169.7923
H2O	85.6626
NAOH	0.0
H3O+	0.0
NA+	0.0
CN-	0.0
OH-	0.0

```
  NACN(S)                0.0
  NAOH:(S)               0.0
  NAOH(S)                0.0
  CO3--                  0.0
  HCO3-                  0.0
  SODIU-01               0.0
  SODIU-02               0.0
  AMMON-01               0.0
  DIAMM-01               0.0
  NH4+                   0.0
  H2PO4-01               0.0
  HPO4--01               0.0
TOTAL FLOW:
  LBMOL/HR             744.7961
  LB/HR                2.1958+04
  CUFT/HR              3.1601+05
STATE VARIABLES:
  TEMP   F             122.0000
  PRES   PSIA           14.6959
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL           -1.1650+04
  BTU/LB              -395.1408
  BTU/HR              -8.6765+06
ENTROPY:
  BTU/LBMOL-R            1.0614
  BTU/LB-R             3.6001-02
DENSITY:
  LBMOL/CUFT           2.3569-03
  LB/CUFT              6.9486-02
AVG MW                  29.4819

33
--

STREAM ID               33
FROM :                  E-105
TO   :                  ----
CLASS:                  MIXCISLD
TOTAL STREAM:
  LB/HR                471.7892
  BTU/HR              -3.1989+06
SUBSTREAM: MIXED
PHASE:                  LIQUID
COMPONENTS: LBMOL/HR
  CH4                    0.0
  NH3                    0.0
  CO2                    0.0
  HCN                    0.0
  CO                     0.0
  H2                     0.0
  O2                     0.0
  N2                     0.0
  H2O                   26.1883
  NAOH                   0.0
  H3O+                 1.0950-07
  NA+                    0.0
  CN-                    0.0
  OH-                  1.0950-07
  NACN(S)                0.0
  NAOH:(S)               0.0
  NAOH(S)                0.0
```

```
  CO3--                     0.0
  HCO3-                     0.0
  SODIU-01                  0.0
  SODIU-02                  0.0
  AMMON-01                  0.0
  DIAMM-01                  0.0
  NH4+                      0.0
  H2PO4-01                  0.0
  HPO4--01                  0.0
TOTAL FLOW:
  LBMOL/HR                 26.1883
  LB/HR                   471.7892
  CUFT/HR                   7.6485
STATE VARIABLES:
  TEMP   F                122.0000
  PRES   PSIA              14.6959
  VFRAC                     0.0
  LFRAC                     1.0000
  SFRAC                     0.0
ENTHALPY:
  BTU/LBMOL             -1.2215+05
  BTU/LB                -6780.4292
  BTU/HR                -3.1989+06
ENTROPY:
  BTU/LBMOL-R             -37.5232
  BTU/LB-R                 -2.0829
DENSITY:
  LBMOL/CUFT                3.4240
  LB/CUFT                  61.6836
AVG MW                     18.0153

34
--

STREAM ID                  34
FROM :                     P-102
TO   :                     E-106
CLASS:                     MIXCISLD
TOTAL STREAM:
  LB/HR                 2.1958+04
  BTU/HR               -8.0669+06
SUBSTREAM: MIXED
PHASE:                     VAPOR
COMPONENTS: LBMOL/HR
  CH4                       0.0
  NH3                       0.0
  CO2                       0.0
  HCN                       0.0
  CO                        0.0
  H2                        0.0
  O2                      489.3412
  N2                      169.7923
  H2O                      85.6626
  NAOH                      0.0
  H3O+                      0.0
  NA+                       0.0
  CN-                       0.0
  OH-                       0.0
  NACN(S)                   0.0
  NAOH:(S)                  0.0
  NAOH(S)                   0.0
  CO3--                     0.0
  HCO3-                     0.0
  SODIU-01                  0.0
```

SODIU-02	0.0
AMMON-01	0.0
DIAMM-01	0.0
NH4+	0.0
H2PO4-01	0.0
HPO4--01	0.0
TOTAL FLOW:	
LBMOL/HR	744.7961
LB/HR	2.1958+04
CUFT/HR	2.3435+05
STATE VARIABLES:	
TEMP F	235.7126
PRES PSIA	23.6959
VFRAC	1.0000
LFRAC	0.0
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	-1.0831+04
BTU/LB	-367.3763
BTU/HR	-8.0669+06
ENTROPY:	
BTU/LBMOL-R	1.3987
BTU/LB-R	4.7442-02
DENSITY:	
LBMOL/CUFT	3.1781-03
LB/CUFT	9.3696-02
AVG MW	29.4819

35
--

STREAM ID	35
FROM :	E-106
TO :	----
CLASS:	MIXCISLD
TOTAL STREAM:	
LB/HR	2.1958+04
BTU/HR	-7.7060+06
SUBSTREAM: MIXED	
PHASE:	VAPOR
COMPONENTS: LBMOL/HR	
CH4	0.0
NH3	0.0
CO2	0.0
HCN	0.0
CO	0.0
H2	0.0
O2	489.3412
N2	169.7923
H2O	85.6626
NAOH	0.0
H3O+	0.0
NA+	0.0
CN-	0.0
OH-	0.0
NACN(S)	0.0
NAOH:(S)	0.0
NAOH(S)	0.0
CO3--	0.0
HCO3-	0.0
SODIU-01	0.0
SODIU-02	0.0
AMMON-01	0.0
DIAMM-01	0.0

NH4+	0.0
H2PO4-01	0.0
HPO4--01	0.0
TOTAL FLOW:	
LBMOL/HR	744.7961
LB/HR	2.1958+04
CUFT/HR	2.9402+05
STATE VARIABLES:	
TEMP F	302.0000
PRES PSIA	20.6959
VFRAC	1.0000
LFRAC	0.0
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	-1.0346+04
BTU/LB	-350.9430
BTU/HR	-7.7060+06
ENTROPY:	
BTU/LBMOL-R	2.3328
BTU/LB-R	7.9126-02
DENSITY:	
LBMOL/CUFT	2.5332-03
LB/CUFT	7.4683-02
AVG MW	29.4819

36
--

STREAM ID	36
FROM :	SEP-102
TO :	----
CLASS:	MIXCISLD
TOTAL STREAM:	
LB/HR	1.7647+04
BTU/HR	-1.4920+07
SUBSTREAM: MIXED	
PHASE:	MIXED
COMPONENTS: LBMOL/HR	
CH4	0.0
NH3	7.3049-06
CO2	8.6200-11
HCN	1.4997-10
CO	8.1428-09
H2	0.0
O2	0.0
N2	1.5861-11
H2O	3.0921
NAOH	0.0
H3O+	4.6024-20
NA+	6.4965
CN-	0.1597
OH-	6.3548
NACN(S)	5.0504
NAOH:(S)	0.0
NAOH(S)	0.0
CO3--	2.9504-04
HCO3-	1.8941-04
SODIU-01	0.0
SODIU-02	0.9966
AMMON-01	0.0
DIAMM-01	0.0
NH4+	0.0
H2PO4-01	0.0
HPO4--01	0.0

```
TOTAL FLOW:
  LBMOL/HR              22.1505
  LB/HR                670.4520
  CUFT/HR                6.2428
STATE VARIABLES:
  TEMP   F             140.0970
  PRES   PSIA           14.6959
  VFRAC                  0.0
  LFRAC                  0.7270
  SFRAC                  0.2730
ENTHALPY:
  BTU/LBMOL           -1.0194+05
  BTU/LB              -3367.7626
  BTU/HR              -2.2579+06
ENTROPY:
  BTU/LBMOL-R          -21.1959
  BTU/LB-R              -0.7003
DENSITY:
  LBMOL/CUFT             3.5482
  LB/CUFT              107.3968
AVG MW                  30.2681

SUBSTREAM: CISOLID      STRUCTURE: CONVENTIONAL
COMPONENTS: LBMOL/HR
  CH4                    0.0
  NH3                    0.0
  CO2                    0.0
  HCN                    0.0
  CO                     0.0
  H2                     0.0
  O2                     0.0
  N2                     0.0
  H2O                    0.0
  NAOH                   0.0
  H3O+                   0.0
  NA+                    0.0
  CN-                    0.0
  OH-                    0.0
  NACN(S)              346.3974
  NAOH:(S)               0.0
  NAOH(S)                0.0
  CO3--                  0.0
  HCO3-                  0.0
  SODIU-01               0.0
  SODIU-02               0.0
  AMMON-01               0.0
  DIAMM-01               0.0
  NH4+                   0.0
  H2PO4-01               0.0
  HPO4--01               0.0
TOTAL FLOW:
  LBMOL/HR             346.3974
  LB/HR               1.6976+04
  CUFT/HR              166.4626
STATE VARIABLES:
  TEMP   F             140.0970
  PRES   PSIA           14.6959
  VFRAC                  0.0
  LFRAC                  0.0
  SFRAC                  1.0000
ENTHALPY:
  BTU/LBMOL           -3.6553+04
  BTU/LB               -745.8739
  BTU/HR              -1.2662+07
```

```
ENTROPY:
  BTU/LBMOL-R            -6.9918
  BTU/LB-R               -0.1427
DENSITY:
  LBMOL/CUFT              2.0809
  LB/CUFT               101.9813
AVG MW                   49.0075

NA2CO3
------

STREAM ID                NA2CO3
FROM :                   E-103
TO   :                   ----
CLASS:                   MIXCISLD
TOTAL STREAM:
  LB/HR                 422.7048
SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  CH4                     0.0
  NH3                     0.0
  CO2                     0.0
  HCN                     0.0
  CO                      0.0
  H2                      0.0
  O2                      0.0
  N2                      0.0
  H2O                     0.0
  NAOH                    0.0
  H3O+                    0.0
  NA+                     7.9764
  CN-                     0.0
  OH-                     0.0
  NACN(S)                 0.0
  NAOH:(S)                0.0
  NAOH(S)                 0.0
  CO3--                   3.9874
  HCO3-                 7.5772-04
  SODIU-01                0.0
  SODIU-02                0.0
  AMMON-01                0.0
  DIAMM-01                0.0
  NH4+                    0.0
  H2PO4-01                0.0
  HPO4--01                0.0
TOTAL FLOW:
  LBMOL/HR               11.9646
  LB/HR                 422.7048
  CUFT/HR              6771.0808
STATE VARIABLES:
  TEMP   F              187.1619
  PRES   PSIA            14.6959
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
AVG MW                   35.3297

VAP
---

STREAM ID                VAP
FROM :                   SEP-102
TO   :                   ----
```

```
CLASS:                      MIXCISLD
TOTAL STREAM:
  LB/HR                     471.7892
  BTU/HR                  -3.1904+06
SUBSTREAM: MIXED
PHASE:                      LIQUID
COMPONENTS: LBMOL/HR
  CH4                         0.0
  NH3                         0.0
  CO2                         0.0
  HCN                         0.0
  CO                          0.0
  H2                          0.0
  O2                          0.0
  N2                          0.0
  H2O                        26.1883
  NAOH                        0.0
  H3O+                     1.4540-07
  NA+                         0.0
  CN-                         0.0
  OH-                      1.4540-07
  NACN(S)                     0.0
  NAOH:(S)                    0.0
  NAOH(S)                     0.0
  CO3--                       0.0
  HCO3-                       0.0
  SODIU-01                    0.0
  SODIU-02                    0.0
  AMMON-01                    0.0
  DIAMM-01                    0.0
  NH4+                        0.0
  H2PO4-01                    0.0
  HPO4--01                    0.0
TOTAL FLOW:
  LBMOL/HR                   26.1883
  LB/HR                     471.7892
  CUFT/HR                     7.6868
STATE VARIABLES:
  TEMP    F                 140.0970
  PRES    PSIA               14.6959
  VFRAC                       0.0
  LFRAC                       1.0000
  SFRAC                       0.0
ENTHALPY:
  BTU/LBMOL               -1.2183+05
  BTU/LB                  -6762.3533
  BTU/HR                  -3.1904+06
ENTROPY:
  BTU/LBMOL-R               -36.9719
  BTU/LB-R                   -2.0523
DENSITY:
  LBMOL/CUFT                  3.4069
  LB/CUFT                    61.3767
AVG MW                       18.0153
```

Section 26: Appendix E

April 6, 2018

Parth Desai
UPENN
1 Benjamin Ct.
Sewell, NJ. 08080

Subject: Budget Estimate for Model S-800 & S-900 Pusher Centrifuges
B&P reference: UPENN Senior Capstone Design Project Inquiry

Dear Parth:

B&P Littleford proposes to you an S-800 & S-900 Pusher Centrifuge with 304/316 wetted components. This includes the equipment and services outlined on the following pages. This is based on the information provided on the “contact us” form from our website.

We thank you for this opportunity. We look forward to providing you with a formal quotation, upon request and clarification of the scope of supply desired. We will be contacting you shortly to further discuss the subject budget quotation with you.

Sincerely,

Aaron E. Anderson
Territory Manager
B&P Littleford LLC
1000 Hess Ave.
Saginaw, MI. USA

Main office: 989-757-1300
Cell number: 989-295-8714
aanderson@bplittleford.com
www.bplittleford.com

Equipment Specification

B&P PUSHER CENTRIFUGE

I. General Equipment Specifications

		S-600	S-800	S-900
Normal Centrifugal Force		380xg	370xg	315xg
Nominal Capacity	**mtph**	18	23	45
	stph	20	25	50
Typical Motor Requirements (Single Motor)	**kw**	30	37	75
	hp	40	50	100
Approximate Stroke Length	**mm**	75	75	85
	in	3	3	3.38
Approximate Stroke Frequency (adjustable)	**SPM**	30-40	30-40	30-44
Basket Diameter	**mm**	635	812	914
	in	25	32	36
Basket Length	**mm**	508	508	597
	in	20	20	23.5
Length	**mm**	2515	2743	3429
	in	99	108	135
Width	**mm**	1575	1880	2591
	in	62	74	102
Height	**mm**	1422	1295	1778
	in	56	51	70
Weight	**kg**	3636	4091	7909
	lb	8000	9000	17400
Shipping Weight with Motor (Approximate)	**kg**	3,600	4,100	7,900
	lb	8,000	9,000	17,400

* Nominal capacities in tons per hour for granulated salt, discharged at 3% moisture from a 50% weight solids feed slurry, with 40% of the crystals greater than 500 micron (35 mesh) and 99% greater than 150 micron (100 mesh). Solids bulk density of 1125 kg/cu.meter (70 lbs./cu.ft).

** Includes internally-mounted motor.

II. <u>Material of Construction</u>

A. <u>Non-process contacted parts are constructed of carbon steel.</u>

B. <u>Process contacted parts:</u>

1. 304/316 Stainless

III. <u>General Description of B&P Pusher Centrifuge Dewatering System</u>

- Process Housing ○ Cage/Basket ○ Screen ○ Shafting Assembly ○ Bearings ○ Pusher Plate ○ Integral Hydraulic System
- Drive
- Base

- **<u>Optional features available at an additional price include</u>:**
  - Manifold Backwash System
  - Local Control Panel

<u>Centrifuge System</u> consists of the following major sub-systems or components:

- **<u>Process Housing</u>:**
  Fabricated design providing segregation of discharged solids from the centrate, and supporting the slurry feed pipe and cake wash lines

- **<u>Basket</u>:**
  The cage basket is a centrifugally-cast design that has milled, oblong holes for maximum drainage

- **<u>Screen</u>**
  B&P-designed, wedge slot, “B” profile screen of single-piece construction

- **<u>Shafting Assembly</u>:**
  A hollow shaft fitted to the basket by a precision taper, and a solid shaft fitted to the pusher plate by a second precision taper. The inner shaft (solid) has a hydraulicallyoperated piston at the end opposite to the pusher plate.
- **<u>Bearings</u>:**
  The rotating assembly is supported by anti-friction bearings

- **Pusher Plate:**
  The pusher plate and inlet funnel assembly are mounted on the tapered end of the inner (solid) shaft with a precision fit.

- **Integral Hydraulic System:**
  The hydraulic control is automatic. A vane-type pump supplies oil flow for the hydraulic circuit.

- **Drive:**
  Driven by a single electric motor through static-conducting "V"-belts

- **Base:**
  The unit is supplied with B&P's a fabricated base, which provides support for the rotating assembly and process housings

- **Manifold Backwash System:**
  The manifold consists of a series of pigtails with wash nozzles in the process housing

- **Local Control Panel:**
  Wall-mounted, NEMA 4/IP 65 non-explosion-proof, pre-wired control and indication

BUDGETARY EQUIPMENT PRICING				
ITEM	DESCRIPTION	UNIT PRICE U.S. $	QTY	EXTENDED PRICE U.S. $
1	**Model S-800 Pusher Centrifuge – 304/316**	**$552,000**	**1**	**$552,000**
2	**Model S-900 Pusher Centrifuge – 304/316**	**$700,000**	**1**	**$700,000**
	Operator Control Panel	$20,946		
	Vibration Isolators	$7,709		
	PLC Controls	$34,475		
	Explosion Proof	$59,725		
	Stroke Hesitation	$4,847		
	Manifold Backwash	$4,908		
	B&P Standard Packing / Crating			**Included**
TOTAL PRICE ITEMS (FCA B&P Dock)				**Note Above Pricing**

Basis

B&P's <u>Standard Terms and Conditions F 701 F</u> shall govern all orders and transactions. Any deviations must be in writing and stated explicitly in the quotation.

Validity

Pricing is budgetary and subject to change without notice. Firm pricing can be offered upon request for a formal quote.

Delivery Period

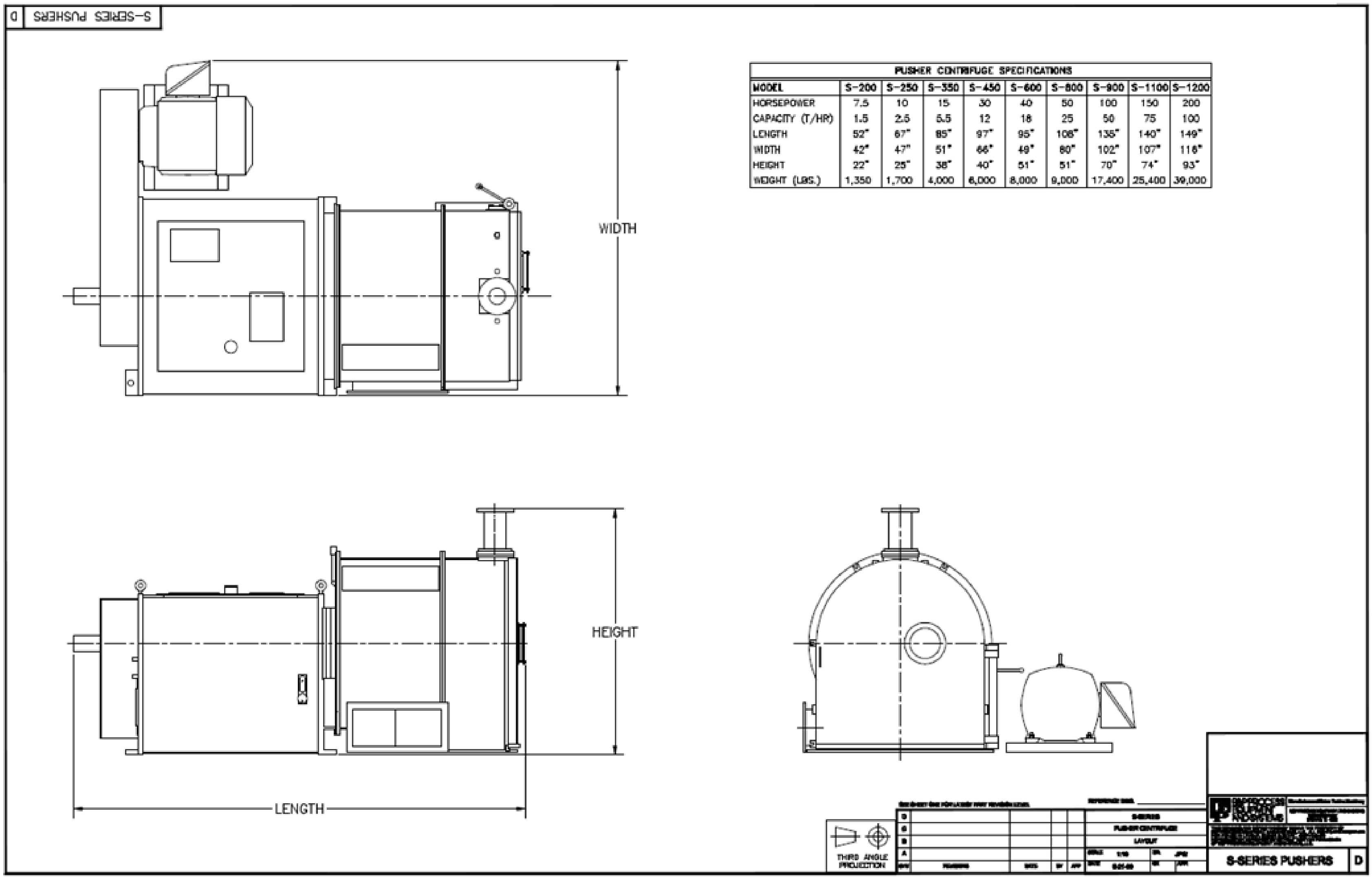
F.C.A. (B&P Dock) delivery is Thirty-Eight (38) weeks. The delivery is estimated, based on shop load and engineering backlog at the time of the offer.

Payment Terms

To be negotiated

Start-Up Service

B&P's mechanical, electrical and process start-up field service personnel are available for assistance toward operational maintenance and training of the plant personnel. Services can be purchased separately, or included with this equipment purchase.



PUSHER CENTRIFUGE SPECIFICATIONS									
MODEL	S–200	S–250	S–350	S–450	S–600	S–800	S–900	S–1100	S–1200
HORSEPOWER	7.5	10	15	30	40	50	100	150	200
CAPACITY (T/HR)	1.5	2.5	5.5	12	18	25	50	75	100
LENGTH	52"	67"	85"	97"	95"	108"	135"	140"	149"
WIDTH	42"	47"	51"	66"	49"	80"	102"	107"	116"
HEIGHT	22"	25"	38"	40"	51"	51"	70"	74"	93"
WEIGHT (LBS.)	1,350	1,700	4,000	6,000	8,000	9,000	17,400	25,400	39,000

TECHNICAL DATA AND OFFER

ROLLER PRESS ARP-5

06.04.2018

Mr. PARTH DESAI

OFFER – ROLLER PRESS FOR SODIUM CYANIDE BRIQUETTING

1. Productivity : 8 T/H
2. Product bulk density (sodium cyanide) : 1.600 g/cm3
3. Consumed energy : 380 - 415 V 50/60 Hz
4. General consumed and Installed power : 65,2kW Total
   - Roller Press : 55 kW
   - Roller Press Feeder : 4kW
   - Feeder doors : 2 x 1,1kW
   - Hydraulic unit : 4kW
5. Fraction of sodium cyanide for briquetting : +0 -3,5mm
6. The maximal moisture of sodium cyanide : 3%
7. Term of manufacturing : 90 days
8. Assembly time : 0 days
9. Occupied area equipment : 5 m2
10. Area for storage of finished products : 50 m2
11. Height of the room - not less : 5m min.
12. Warranty : 1 year
13. Operating mode : Automatic and Manual
14. The size and shape of briquettes : 45x45x26 According to customer request
15. Roller press with a force pressing : 0 - 250 Bar
16. Attendants : 1 people per shift
17. Roller Press Price : 144.000 Euro Ex-Work Turkey
18. Payment method : Remittance with an advance payment
19. Service : Service is charged separately to customers
20. Spare parts of briquetting plant : Charged separately to customers
21. If during the warranty period will be failure, a broken part is replaced with pre-purchased parts buyers due to the Seller and on-site details of the new Seller agree to deliver the new parts.

22. Electrical equipment has a degree of protection of at least IP55 and IP54.
23. Electric motors : Siemens, Wat, Gamak, Volt, Yilmaz
24. Feeder Gear : Yilmaz
25. Roller Press Gear : Acan - Custom Manufacturing
26. Automatics and PLC : Schneider, Omron, Ge, Fuji, Delta, Abb
27. Bearings : Urb, Kyk, Skf, Fag, Zkf, Timken
28. Price is valid for 30 days after the above specified date.

Regar
ds Fuat
CAN
fuatcan@acanmachine.com
www.acanmachine.com

ROLLER PRESS DATA

Mixer-Feeder:

- Vertical gravitationally screw feeding distributor;
- Feeder electric motor with gearbox 4 kW / 380V; 60 Hz. – IP54
- Feeder door electric motor with gearbox 2 x 1,1 kW / 380V; 60 Hz. – IP54 Roller Press:
- Reduction gearing;
- Electric motor 55 kW / 380V; 60 Hz. – IP54 Hydraulic System:
- Hydraulic system electric motor 4 kW / 380V; 60 Hz – IP-54;
- Reciprocating hydraulic pump - Hydraulic pistons (4 unit),
- Roller press works with 4 hydraulic pistons and they reach to pressure from 0 to 250 bars. Control panel:
- Manual Start/Stop control panel.
- Roller Press 55 kW electric motor is driven to.
- Roller Press speed settings, and forward-backward movements are controlled manual control panel.
- This electrical panel done with the help of the inverters.
- The inverter, the playing speed settings for increasing or decreasing capacity. - Equipment protection degree - IP54 Gearbox (dual output reducer): - 1485 rpm – input;

- 14,5 rpm max. – output;
- 1,5 service factor,
- Heavy type of work, the four-stage, target moment 3500Hm.

Frame:

- Frame of the press is made of strengthened steel design ST 37.
- After welding (MIG Wires) works frame sends on heat treatment.
- All welding are done with electrodes for steel materials.

Tyre:

- The diameter of tyre Ø650mm is made of a steel material DIN-1.4122 (X35CrMo17) - Heat treatment bandage to 650 HV (Vickers).
- Quantity of tyre - 2 pieces.

Roll Shaft:

- The diameter of roll shaft Ø270mm is made of the forged steel material 1.7225 (42CRMo4+H), - Quantity of roll shaft - 2 pieces.

Bearings:

- 22388 – 4 pieces.

Coupling:

- ACAN Moving coupling – 1 piece.

Coupling:

- ACAN Adjustable coupling – 1 piece.

Electrical:

Cables

- NYY-J/NYCY – DIN VDE 0276
- LIYCY DIN VDE 0812

Electric motors,

- GAMAK, DEG, YILMAZ, WAT, ELEKTROMER

Electrical panels,

- TEMPO, ERSOY end other

Circuit breakers,

- SCHNEIDER

Panel Internal material,

- SCHNEIDER, WEIDMULLER, METE ERENRGY

Etc

Automation and computerized management:

Inverter,

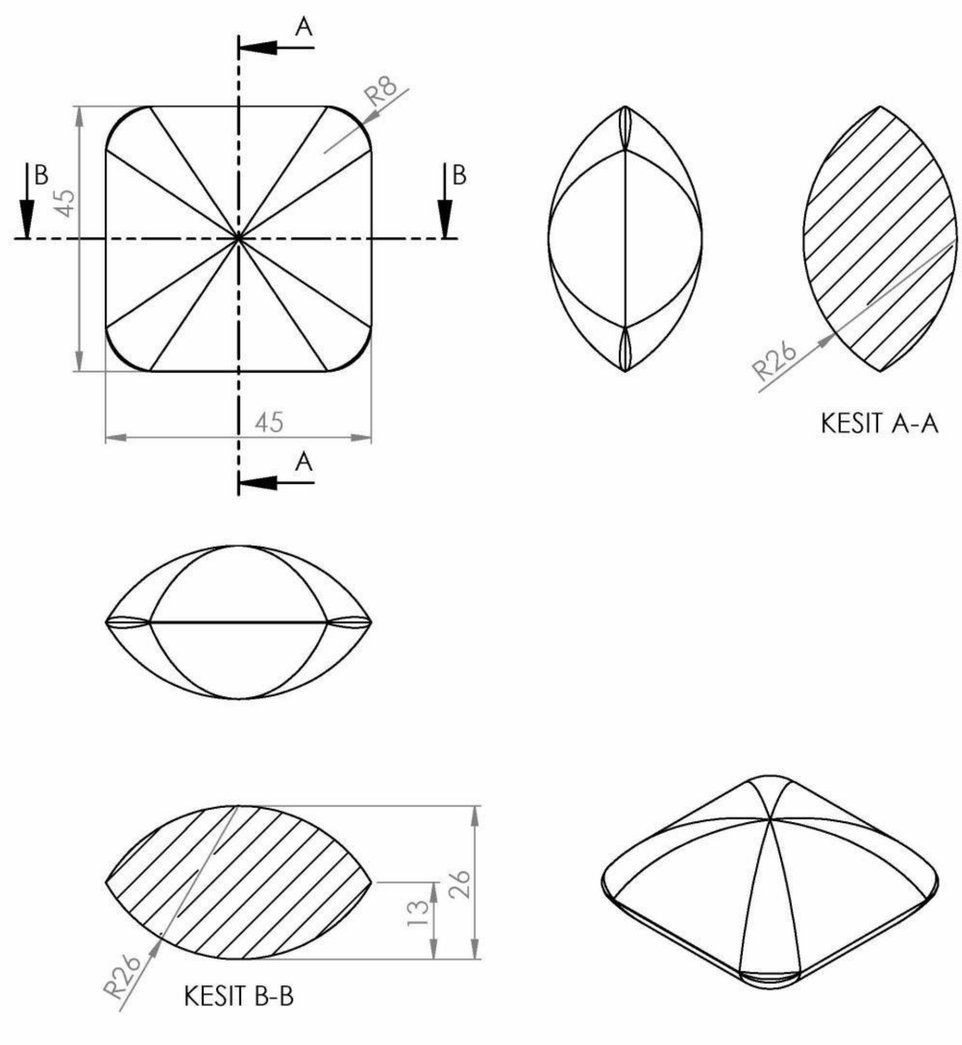
- FUJI

Software,

- LEDR

Control panel,
Inside the panel material,

- SHAIDER Etc.



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KONTROL	Fuat CAN			
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